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Space systems — Thermal control coatings for spacecraft — General requirements

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National foreword

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Foreword

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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).

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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 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

This International Standard explains technical information for TCCs selection and application required to confirm their compliance with the requirements of the thermal control for spacecraft.

This International Standard classifies thermal control coatings in accordance with their usage in passive and/or active thermal control subsystems for reduction of external heat absorption or regulation of radiant heat exchange between on-board equipment on spacecraft, their general properties, and their special characteristics for space environment applications.

This International Standard also contains special recommendations for surface preparation, application of coating systems and curing, and establishes requirements for test methods on estimating properties of thermal control coatings according to their target use.

Space systems — Thermal control coatings for spacecraft — General requirements

1 Scope

This International Standard defines general requirements for thermal control coatings (TCC) that are applied on metallic and/or non-metallic surfaces of spacecraft and payloads in order to provide the following thermo-optical properties:

— α_S: solar absorptance;

— ε: emittance.

The function of TCC is to reduce external heat absorption and/or to regulate radiant heat exchange between on-board equipment on spacecraft.

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 9117-1:2009, *Paints and varnishes — Drying tests — Part 1: Determination of through-dry state and through-dry time*

ISO 14624-3, *Space systems — Safety and compatibility of materials — Part 3: Determination of offgassed products from materials and assembled articles*

3 Terms, definitions, and abbreviated terms

3.1 Terms and definitions

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

3.1.1
active thermal control system
system where the active thermal control method is used

Note 1 to entry: The active thermal control method is the procedure to control the temperature using mechanical mobile components or fluid, using electric energy from a heater, changing the component's thermo-physical property, or utilizing another technology to change/control the temperature.

[SOURCE: JERG-2–310:2009]

3.1.2
coating
continuous layer formed from a single or multiple application of a coating material to a substrate

[SOURCE: ISO 4618:2006]

3.1.3
coating material
product in liquid, paste, or powder form, that, when applied to a substrate, forms a film possessing protective and/or other specific properties

[SOURCE: ISO 4618:2006]

3.1.4
coating process
process of application of a coating material to a substrate, such as dipping, spraying, roller coating, brushing

[SOURCE: ISO 4618:2006]

3.1.5
coating system
combination of all coats of coating materials which are to be applied or which have been applied to a substrate

[SOURCE: ISO 4618:2006]

3.1.6
emissivity
emittance
ε

$$\varepsilon = M/Mb$$

where M is the radiant exitance of a thermal radiator, and Mb is the radiant exitance of a blackbody at the same temperature

Note 1 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);[7]

— **Spectral or monochromatic**: If they are related to a spectral interval centered on the wavelength λ;[7]

— **Hemispherical**: If they are related to all directions along which a surface element can emit or receive radiation;[7]

— **Directional**: If they are related to the directions of propagation defined by a solid angle around the defined direction;[7]

— **Normal**: If they are related to the normal direction of propagation or incidence to the surface.[7]

[SOURCE: ISO 80000-7:2008]

[SOURCE: ISO 16378]

3.1.7
paint
pigmented coating material which, when applied to a substrate, generally forms an opaque film having protective or specific technical properties

[SOURCE: ISO 4618:2006]

3.1.8
paint film
intact coating that is formed by applying one or multiple layers of coating materials on a substrate

3.1.9
passive thermal control system
system where the passive thermal control method is used

Note 1 to entry: The passive thermal control method is the procedure to control the temperature of the component within the specified range by adjusting the paths of conduction and radiation, and by the selection of geometric form of each surface and thermo-physical property of the spacecraft.

[SOURCE: JERG-2–310:2009]

3.1.10
payload
set of space segment elements (parts of a space system placed in space to fulfill the space mission objectives)

Note 1 to entry: A spacecraft payload is a set of instruments or equipment that performs the user mission.

Note 2 to entry: A launcher payload is a set of space segment elements carried into space in accordance with agreed position, time, and environmental conditions.

[SOURCE: ISO 10795:2011]

3.1.11
primer
paint that has been formulated for use as a priming coat on prepared surfaces

3.1.12
priming coat
first coat of a coating system

3.1.13
solar absorptance
α_S
ratio of the solar radiant flux absorbed by a material (or body) to the radiant flux of the incident radiation

3.1.14
substrate
surface to which a coating material is applied or is to be applied

3.1.15
thermal control coating
TCC
coating that is used to maintain certain temperature conditions of an object by way of establishing the balance between the heat absorbed from an environment and/or emitted by internal heat sources and the energy radiated by object’s surface in an environment

3.1.16
varnish
clear coating material which, when applied to a substrate, forms a transparent film

3.1.17
witness sample
sample pieces that represent the coated product

Note 1 to entry: They shall be made in the form of the flat plates using the same coating material with the product, and coated simultaneously. Used for destructive test and test that requires limited size of specimen.

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this International Standard.

BOL	beginning of life
EMC	electromagnetic compatibility
EOL	end-of-life
ESD	electrostatic discharge
TCC(s)	thermal control coating(s)
TCS(s)	thermal control (sub) system(s)
QA	quality assurance
UV	ultraviolet
VUV	vacuum ultraviolet

4 General

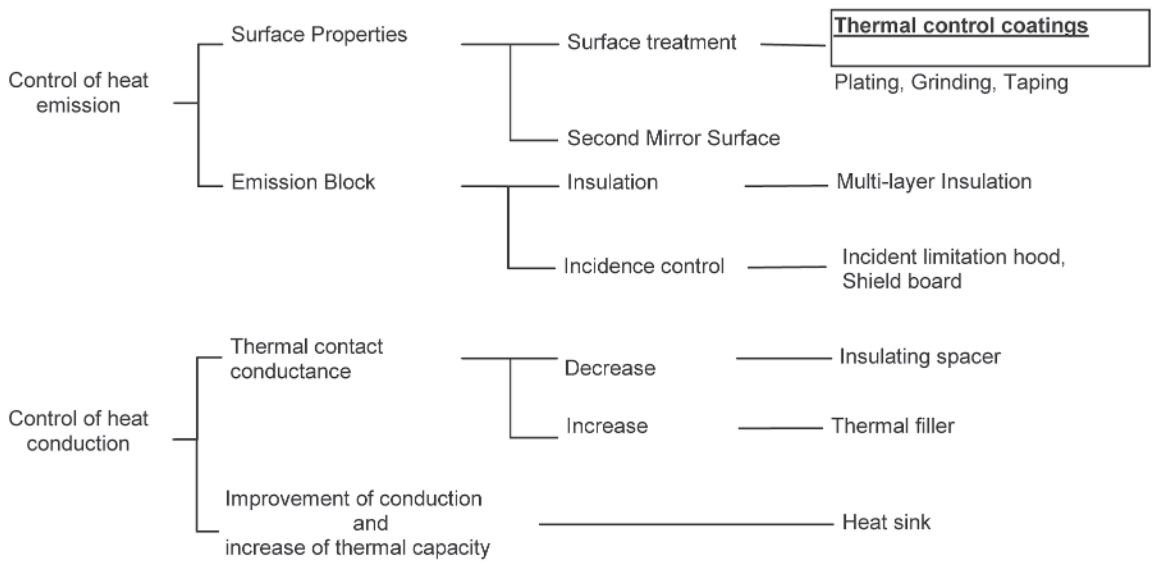

Figure 1 — The mapping of thermal control coatings relative to each passive thermal control material

The action of the space environment strongly depends on the spacecraft service conditions. These are defined by the orbits where spacecraft are intended to operate.

Heat sources which determine the temperature of a spacecraft are mainly solar rays and earth albedo. The quantity of heat emitted from a spacecraft is equal to the sum of heat input and the quantity of internal heat produced from the all equipment of a spacecraft.

Nevertheless, there are general factors that exert influence on spacecraft serviceability and efficiency: vacuum, electromagnetic solar radiation, including UV-radiation and VUV-radiation, ionizing radiations, atomic oxygen, temperature, contamination, micrometeoroids, and debris environment effects.

When in service, undesirable effects can occur, such as electrostatic charging, generation of spacecraft outer atmosphere, and alternating thermal loads.

TCC are generally damaged by UV and charged particle exposure. In addition, at altitudes of roughly 200 km-600 km erosion of some TCC can occur due to atomic oxygen. Bleaching or whitening of UV/charged particle induced damage of these coatings can also occur from atomic oxygen exposure.

TCCs are the elements of passive and/or active TCSs for temperature regulation of spacecraft. The location of thermal control coatings in relation to other passive thermal control materials is shown in Figure 1 above.

TCCs are applied on spacecraft surfaces, individual units, assemblies, and devices that are to be temperature-controlled. They are used to maintain the preset temperature conditions of a spacecraft by establishing the balance between the heat absorbed from an environment and/or emitted by on-board sources, the energy redistributed between equipment and spacecraft structure, and the energy radiated in environment.

The thermo-optical properties of a TCC are used in TCSs design. TCC shall meet the specification requirements at the BOL and maintain required properties at the EOL of the spacecraft.

EMC/ESD, ageing, difference of properties between the beginning and the end of service life are defined by service conditions and purposes of spacecraft. These properties are measured when candidate TCC materials are under consideration for a TCS in the design stage.

The scope depends on the coating to be tested and requirements of designer and/ or production engineer.

4.1 Functionality

With regard to their functionality, determined by the coating's ability to absorb or reflect the radiant energy, the thermal control coatings can be classified as follows:

— **I:** true absorber ($\alpha_S \rightarrow 1$, $\varepsilon \rightarrow 1$);

— **II:** solar reflector ($\alpha_S \rightarrow 0$, $\varepsilon \rightarrow 1$);

— **III:** solar absorber ($\alpha_S \rightarrow 1$, $\varepsilon \rightarrow 0$);

— **IV:** true reflector ($\alpha_S \rightarrow 0$, $\varepsilon \rightarrow 0$).

4.1.1 Class I

Class I (black) TCCs absorb the heat from higher temperature objects and transmit the heat to lower temperature one, and promote intensification of the radiant heat transfer between surfaces of devices and units, as well as between devices, units, and environment.

Black TCCs are mainly applied to inner surfaces. They are applied on surfaces of spacecraft optical devices (radiation-measuring instruments, analog of an ideal radiator), on lens cells, blends, and barrels of optical devices (cameras, telescopes, scanners of a terrestrial surface), and on external surfaces to absorb radiation from the sun. Additionally, these coatings prevent the reflection of light from one surface to another.

4.1.2 Class II

Class II (white) TCCs reflect incident light and thermal radiation from heat sources such as solar rays and earth albedo to maintain the temperature of spacecraft design components within the working range and increase efficiency of TCSs.

White TCCs are mainly applied to outer surfaces. Class II TCCs can also be used to sink heat in environments to lower temperature of spacecraft members.

4.1.3 Class III

Class III TCCs are used on facilities that function periodically and require ingress of energy when the facility is off to maintain a stable temperature and prevent exceeding low temperature limits.

4.1.4 Class IV

Class IV TCCs are mainly applied on surfaces subjecting to simultaneous heating by propulsion jets and subject to convective cooling.

4.2 Basic components

The basic components of TCCs are binders and pigments.

Paints generally have both of these components; but other coatings, such as plasma spray TCC can use only one, usually a pigment.

Usual binders are either organic (for example, silicone, polyurethane, fluorocarbon, etc) or inorganic (for example, silicates) components.

Pigments which can be used include oxides and fluorides of metals, metals, and also complex and simple salts.

5 Selection

TCCs should be selected considering their thermo-optical and environmental resistance properties, advantages and disadvantages, meet mission requirements, and perform the required system functional objectives.

To ensure working capacity of spacecraft, selection of TCC or coating system (class of coating, structure, paints, and primers) should be made by the designer depending on requirements for their properties and type of material to which a coating material is applied and service conditions.

When selecting TCCs of classes I and II, primary characteristics to be considered are shown in Table 1 below.

When selecting TCCs of classes III and IV, the list of primary characteristics is determined by designers depending on service conditions of the equipment, on which TCC is applied.

Table 1 — Primary characteristics to be considered when selecting TCCs of Class I and II

Coating type	TCC-I		TCC-II	Remarks on selection
	Internal surface	External surface	External surface	
Thickness	+	+	+	Coating thickness is determined considering adhesion, hiding power, and weight. Required thickness to achieve its thermo-optical function is different depending on types of coating materials.
Adhesion	+	+	+	The adhesion of TCCs is different depending on the types of coating materials and materials to be coated. The TCCs which demonstrates a high level of adhesion shall be selected regarding adhesion test results of the TCC to different materials.

Table 1 *(continued)*

Coating type		TCC-I		TCC-II	Remarks on selection
		Internal surface	External surface	External surface	
Thermo-optical characteristics	α_S	-	+	+	The appropriate α_S and ε shall be selected regarding internal heat generation and the desired temperature of spacecraft. When internal heat is small, the spacecraft temperature is determined by α_S /ε. Since extended exposure to the space environment will affect thermo-optical properties, special attention is needed.
	ε_n	+	+	+	
Electrical volume resistivity		+	+	+	Reducing surface charging requires controlling electric properties of the surface materials that directly contact with the surrounding plasma. Electrical resistivity should be low enough to reduce possibility of local charging and the resultant electrostatic discharge.
Electrical surface resistance		+	+	+	
Outgassing		+	+	+	Outgassing character of TCC shall fulfill the contamination requirement of the spacecraft. Special care should be taken when the coating is applied on a large area, close to contamination sensitive and/or cryogenic surfaces. The quantity of outgas is different depending on the processing condition such as the spraying and the curing of the coating and the lot of the coating material.
UV-resistance		-	+	+	TCCs which applied outer surface of a spacecraft are subject to strong UV rays. Thermo-optical properties and adhesion are degraded by UV. The amount of UV which a spacecraft receives is determined by the orbital altitude, expected lifetime, attitude, and geometry of the spacecraft.
Radiation resistance		+	+	+	TCCs shall withstand strong levels of radiation. Thermo-optical properties and adhesion are degraded by radiation. Dose which a spacecraft receives is determined by the orbital altitude, expected lifetime, and shielding effect of the spacecraft.
Atomic oxygen resistance		-	+	+	TCCs which applied outer surface of a spacecraft are exposed to a large quantity of atomic oxygen. Thermo-optical properties and adhesion are affected by atomic oxygen.
Gloss		+	+	+	Class I TCC is sometimes used around optical instruments in purpose of surface reflection prevention. TCC with flat (low gloss) surface should be selected for that purpose.

Table 1 *(continued)*

Coating type	TCC-I		TCC-II	Remarks on selection
	Internal surface	External surface	External surface	
Temperature cycling	+	+	+	TCCs shall withstand temperature cycling. Thermo-optical properties and adhesion are affected by temperature cycling. The cycle is determined by the orbital altitude of spacecraft.
Mass of ejecta[a]	+	+	+	Damage caused by meteoroids and/or debris can result in a potential generation of small debris (ejecta). The amount of ejecta is greater for brittle materials such as inorganic TCC than for ductile materials.

[a] For specific cases, on request of the designer.

General properties of typical TCCs are shown in Annex A.

6 Test methods for TCC

6.1 Visual inspection

Visual inspection shall be performed to the coated product itself. Witness samples approved by the manufacturer shall be used for comparison, if required.

The samples shall be prepared from the materials that are used in spacecraft.

6.2 Coating thickness

The thickness of TCC applied on surfaces is measured by non-destructive methods.

The thickness of TCC shall be measured in three different points on the surface of the product. When the coated surface is greater than 1 m^2, number of measurements should be coordinated with the customer.

Thickness of TCC is not to be measured in hard-to-reach places, on welds, and on edges of the product.

The weight of dried TCC (coating system) will depend on its thickness and shall be calculated in advance to adhere to the requirements of system weight limitation.

6.3 Adhesion

Adhesion of a TCC is determined using preferably the cross-cut tests primarily performed on a witness sample. The cross-cut test on a painted product will be performed with the customer’s approval. Other adhesion tests are also permissible. The subsequent repair of the damaged test areas and/or coating details is mandatory.

The measurement of the coating adhesion in the hard-to-reach places is not mandatory.

The test specimen shall be prepared simultaneously with the coated products.

6.4 Thermo-optical properties

a) The thermo-optical properties shall be measured in the course of/after space environment resistance tests.

b) The measurements shall be performed on the witness samples by the methods referred in Annex A. Other measurement method could be applied with the customer's approval. Measurement method shall be recorded and reported.

c) To measure α_S, ε, and thickness of the TCC applied on metal surfaces, the witness samples are made in the form of the flat plates, one item per product or a batch of products, and coated simultaneously with them.

d) To measure α_S, ε, and thickness of the TCC applied on non-metallic surfaces, the witness samples are made from the same material that is used in the product to be coated.

6.4.1 Method of measurement of α_S

Two test methods are described in this clause.

6.4.1.1 Solar absorptance using a spectrophotometer

The primary method covers the measurement of spectral absorptance (α_S), reflectance, and transmittance of materials using spectrophotometers equipped with integrating spheres.

6.4.1.2 Solar absorptance using the comparative test method

$\boldsymbol{\alpha_S}$ of thermal control coated products is measured using portable photometers and by comparing it with the reference samples. α_S of the reference sample is calculated based on the measurement results of reflectance ($\rho\lambda$) taken using the spectrophotometer and normalize to the solar curve.

Based on the measurement results of the solar radiant reflectance (ρ_S), α_S is calculated as follows:[10]

$$\alpha_S = 1 - \rho_S \tag{1}$$

$$\rho_S = \frac{\int_{\lambda_1}^{\lambda_2} \rho(\lambda) S(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} S(\lambda) d\lambda} \tag{2}$$

where

$\rho(\lambda)$ is the spectral reflectance after 100 % reference correction;

$S(\lambda)$ is the spectral solar irradiance;

$d\lambda$ is typically 1 nm. $d\lambda$ shall be defined considering the sample properties;

λ_1 is smaller than 250 nm;

λ_2 is larger than 2 500 nm.

Solar irradiance spectrum is available in several sources. ASTM E490-00a should be primarily applied. When other spectrum is used, the data source shall be described in test report.

Surface of the witness sample and surface of the measured product shall be similar (same processing, same material, same composition of the TCC covering, and same technology of coating application).

6.4.2 Method of measurement of ε

ε is measured using a thermo-radiometer by comparing the radiation from the measured product surface with the radiation from the blackbody standard surface being at the same temperature.

Other test methods required by national standards can be used for measurement of α_s and ε.

6.4.3 Change of optical characteristics

The measurements and the analysis of $\Delta\alpha_s$ and $\Delta\varepsilon$ of the TCCs shall be performed through tests in special chambers simulating conditions of space environment.

Measurements of optical properties and their changes due to space environment exposure in vacuum are preferable.

$$\Delta\alpha_s = \alpha_{s1} - \alpha_{s0} \tag{3}$$

where

α_{s0} is the solar absorptance before test in special chambers simulating conditions of space environment;

α_{s1} is the solar absorptance after test in special chambers simulating conditions of space environment.

$$\Delta\varepsilon = \varepsilon_1 - \varepsilon_0 \tag{4}$$

where

ε_0 is the emittance before test in special chambers simulating conditions of space environment;

ε_1 is the emittance after test in special chambers simulating conditions of space environment.

6.5 Resistance (electrical surface resistance and electrical volume resistivity)

Electrical surface resistance and electrical volume resistivity of TCCs are measured using the measuring probes and an appropriate voltage or resistance meter. The flat samples should be at least 25 mm × 50 mm. For tubular samples, a diameter of 50 mm minimum is recommended.

The probes should have high conductivity and should provide good electrical contact on the entire contact surface with the sample and should not interfere with the proper measurement of the resistance of the sample under test.

Resistance measurements are performed using the measuring devices having the required accuracy that have the ability to perform measurements within a preset range and allow smooth regulation of the applied test voltage. Measurement atmosphere (humidity, temperature, pressure, etc.) should be described.

TCCs that could have an adverse effect on spacecraft systems and hardware due to their electrical characteristics and properties shall be reviewed by EMI engineering for compliance with program specifications and specifically approved for use on the program.

The measurements shall be performed by the methods referred in Annex A.

6.6 Outgassing

Outgassing character of TCCs shall fulfill the contamination requirement of the spacecraft.

The measurement shall be performed by the methods referred in Annex A.

6.7 UV-resistance

The amount of UV which a spacecraft receives is determined by the orbital altitude, expected lifetime, attitude, and geometry of the spacecraft.

The measurement shall be performed by the methods referred in Annex A.

Change in thermo-optical properties and adhesion of the tested specimen shall be evaluated. Other properties are assessed as required.

6.8 Radiation resistance

Dose which a spacecraft receives is determined by the orbital altitude, expected lifetime, and shielding effect of the spacecraft.

The measurement shall be performed by the methods referred in Annex A.

Change in thermo-optical properties and adhesion of the tested specimen shall be evaluated. Other properties are assessed as required.

6.9 Atomic oxygen resistance

The amount of atomic oxygen which a spacecraft receives is determined by the orbital altitude, expected lifetime, attitude, and geometry of the spacecraft.

The measurement shall be performed by the methods referred in Annex A.

Change in thermo-optical properties and adhesion of the tested specimen shall be evaluated. Other properties are assessed as required.

6.10 Gloss

The measurement shall be performed by the methods referred in Annex A.

6.11 Temperature cycling (influence of temperatures)

TCCs shall function in the temperature range, t ± 150 °C, unless otherwise stated in standard for the individual TCC.

The measurement of the durability of TCCs to determine the influence of high and low temperatures as well as of temperature cycling shall be performed in a special climatic chamber able to simulate the correct environmental conditions.

Tests are performed on witness samples. Change in thermo-optical properties and adhesion of the tested specimen shall be evaluated. Other properties are assessed as required.

6.12 Mass of ejecta

TCCs produce ejecta under micrometeoroid or debris impingement. TCCs with less ejecta are preferable in purpose of debris mitigation.

The measurement shall be performed by the methods referred in Annex A.

7 Requirements for application

a) The TCCs shall have an adhesion with the substrate to which it is applied and suitable for the intended use.

b) The TCCs should be applied in any regulated method, described in coating's normative document.

c) Defects are described in materials' or application standards, or as specified in design documentation.

d) When assembling, manufacturing, marking, and during packing operations; the coated parts shall not be touched and handled with bare hands. A lint-free clean cotton or powder-free surgical gloves shall be used.

If the coated part is touched or handled with protected hands, they shall not move against the coated surfaces.

e) Coating process requirements (method of application, work area requirements, safety measures requirements) should be defined by coating material supplier. All parameters which define the process requirements shall be properly controlled and monitored.

Curing time of a coat and a TCC is determined according to ISO 9117-1. Other methods including domestic ones are also admissible.

Coating material should meet a manufacturer certification.

f) Failure modes: scratches, chips, dirt, and unpainted spots during ground operations. Causes: assembly, transportation, wrapping, unwrapping, atmospheric conditions. All these defects can be repaired with the repair procedures recommended by appropriate TCC manufacturer, if necessary or desired.

8 Safety requirements for TCC application

a) Unless otherwise specified, toxicity requirements for TCCs and the painting process shall meet the requirements specified herein:

b) Some paints and primers used to prepare TCC are toxic, primarily due to the use organic thinners in some of them. When handling paints and primers, a means of individual protection and protective accessories shall be used, and the effects of the materials on the environment should be monitored.

c) Toxicity requirements are not applied for all modules except inhabited ones. In case of application of TCCs inside the inhabited modules, it is necessary to follow ISO 14624-3.

9 Identification

a) Coating materials shall be labelled.

b) The label shall contain the total information to identify unambiguously the TCC according to the normative documentation.

10 Protectors

Protectors are used to maintain solar absorptance and emittance of TCC in the course of storage, and to protect them from damages and contamination during assembly, installation, and transportation. Temporary, easily disposable protectors that are appropriate and allowed to be in contact with the coating, and do not damage or exert influence on it can be used.

Removal of TCC protection material(s) should be done using standard procedures, tools, and materials.

Properties of applicable TCC protection materials are defined in accordance with the requirements of design documentation and taking into consideration material technological normative document.

TCC protection materials are applied, used, and removed in accordance with the process described in appropriate design documentation.

Some kind of white paints turn yellow due to UV emitted by fluorescence lamp. Light insulator should be considered when the UV-sensitive TCC is stored under room and/or solar light.

11 Packing

a) The painted components should be adequately packed to protect the TCCs from damage and dirt during transportation and storage.

b) The type of the package is chosen in accordance with the size and shape of the product to be packed and taking into consideration the materials and components being the part of the product.

c) The type of the package should be specified in the product specification.

12 Production program of quality assurance

12.1 General

a) The person/organization responsible for application of the TCC should have an adequate quality management system such as ISO 9001 certification.

b) The supplier should be requested to identify the production processes and the actions that exert influence on properties of the components that are used to manufacture TCCs, and should also provide the adequate monitoring of these processes and actions.

c) The basic processes and actions for which the appropriate procedures should be developed are the following:

    1) incoming inspection (identification) of raw materials and components;

    2) storage of raw materials and components;

    3) production of TCCs in working conditions;

    4) test methods of the finished products;

    5) marking, packing.

d) Certification: Consumer should perform the incoming inspection of coating to check whether the necessary indicators are in compliance with the certificate of the product.

13 Changes and revisions

13.1 Permissive document

Requirements of a standard can be changed or revised only if there is an approved permissive document. The permissive document is issued by the organization/people that initiates changes or revisions. The document includes the following:

a) number and/or other designation of the change to be issued, designation of the confirmatory document and the date of its approval;

b) the reason for change or revision;

c) lists of pages, points, lines etc. that are to be changed;

d) the copies that are to be changed (if not all of them shall be changed);

e) terms of changes.

13.2 Necessary signatures for the confirmatory document

The confirmatory document should be signed by

a) the initiator of change,

b) the responsible program manager for the space system, and

c) the customer if this was prescribed.

13.3 Record of changes

All changes and revisions should be registered in the record of changes which includes the following:

a) the number of change of the given copy;

b) the designation of the confirmatory document;

c) the date of change of the given copy;

d) the numbers of pages (changed, new, and annulled);

e) the name and the signature of the responsible person for making changes.

NOTE Depending on the project phase, a "*Material review board*" (MRB) shall be convened.

Annex A
(informative)

General properties of TCC-I and TCC-II

Characteristic	Standard values		References
	TCC-I	TCC-II	
1) Colour	black	white	ISO 3668:1998 (GOST 29319–92), *Paints and varnishes —Visual comparison of the colour of paints*
2) Thickness of coating, (μm) (The preferable thickness can be according to the TCC specification or should meet the manufacturer's recommended value)	≤ 100	≤ 150	GOST R 51694–2000 (ISO 2808:2007), *Paints and varnishes — Determination of film thickness*
3) Adhesion	1–2	1–2	ISO 4624:2002, *Paints and varnishes — Pull-off test for adhesion* GOST 15140–78, *Paintwork materials. Methods for determination of adhesion* ISO 2409:2013, *Paints and varnishes — Cross-cut test* ECSS-Q-ST-70–04C, *Space product assurance. Thermal testing for the evaluation of space materials, processes, mechanical parts and assemblies*
4) Optical characteristics: — solar absorptance, α_s — emittance, ε	 ≥ 0,95 ≥ 0,92	 ≤ 0,3 ≥ 0,90	ISO 16378, *Space systems — Measurements of thermo-optical properties of thermal control materials* ASTM E490 –00, (2006), *Standard solar constant and zero air mass solar spectral irradiance tables* ASTM E903–96, *Standard test method for solar absorptance, reflectance, and transmittance of materials using integrating spheres* ECSS-Q-ST-70–09C, *Measurements of thermo-optical properties of thermal control materials*
5) Normal TCC: Electrical volume resistivity, ρ, (Ohm × m) Specific antistatic TCC: Electrical volume resistivity, ρ, (Ohm × m) Electric surface resistance, R, (Ohm)	 ≤ 7 × 10^{14} ≤ 7 × 10^3 1 × 10^6	 ≤ 7 × 10^{14} ≤ 5 × 10^5 1 × 10^6	GOST 6433.2–71, *Solid electrical insulating materials. Methods for evaluation of electrical resistances at d. c. voltages* ASTM-D 257–07, *Electrical surface resistance measurement* IEC 61340–2-3, *Methods of test for determining the resistance and resistivity of solid planar materials used to avoid electrostatic charge accumulation* IEC 60093, *Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials* IEC 60167, *Methods of test for the determination of the insulation resistance of solid insulating materials* ISO 1853, *Conducting and dissipative rubbers, vulcanized or thermoplastic — Measurement of resistivity* ISO 3915, *Plastics — Measurement of resistivity of conductive plastics*

[a] Under preparation.

Characteristic	Standard values		References
	TCC-I	TCC-II	
6) Outgassing: — mass loss, (%) — condensable substances, (%)	 ≤ 1,0 ≤ 0,1	 ≤ 1,0 ≤ 0,1	ASTM E595, *Standard test method for total mass loss and collected volatile condensable materials from outgassing in a vacuum environment* GOST R 50109–92, *Non-metallic materials. Test method for mass loss and content of volatile condensable materials in a vacuum-thermal environment* ECSS-Q-ST-70–02C, *Space product assurance. Thermal vacuum outgassing test for the screening of space materials*
7) UV-resistance Change of solar absorptance, $\Delta\alpha_S$, when subjected to: — solar UV-radiation (exposure - 100 esd) Adhesion	 ≤ 0,005 ≤ 0,005 1–2	 ≤ 0,04 ≤ 0,04 1–2	ECSS-Q-ST-70–06C, *Space product assurance. Particle and UV radiation testing for space materials* ISO/AWI 17851[a] ,*Space environment (natural and artificial) — Space environment simulation at material tests — General principles and criteria*
8) Radiation resistance Change of solar absorptance, $\Delta\alpha_S$, when subjected to: — electrons (fluence - $5{\cdot}10^{16}$ cm^{-2}, energy - 40 keV) — protons (fluence - $5{\cdot}10^{15}$ cm^{-2}, energy - 40 keV) Adhesion	 ≤ 0,005 ≤ 0,005 1–2	 ≤ 0,10 ≤ 0,10 1–2	ISO 15856, *Space systems — Space environment — Simulation guidelines for exposure of non-metallic materials* ISO/AWI 17851[a] , *Space environment (natural and artificial) — Space environment simulation at material tests — General principles and criteria*
9) Atomic oxygen resistance Adhesion	 1–2	 1–2	ASTM E2089 – 00 (2006), *Standard practices for ground laboratory atomic oxygen interaction evaluation of materials for space applications* ISO/AWI 17851[a] , *Space environment (natural and artificial) — Space environment simulation at material tests — General principles and criteria*
10) Gloss 60° Gloss	 3 ± 3	 -	ISO 2813, *Paints and varnishes — Determination of specular gloss of non-metallic paint films at 20 degrees, 60 degrees and 85 degrees*
Temperature cycling from (±100°C), 100 cycles to (±150°C), 1000 cycles: Adhesion	 1–2	 1–2	
Mass of ejecta			ISO 11227, *Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact*

[a] Under preparation.

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[2] ISO 2808:2007, *Paints and varnishes — Determination of film thickness*

[3] ISO 2813:1994, *Paints and varnishes — Determination of specular gloss of non-metallic paint films at 20 degrees, 60 degrees and 85 degrees*

[4] ISO 3248:1998, *Paints and varnishes — Determination of the effect of heat*

[5] ISO 4624:2002, *Paints and varnishes — Pull-off test for adhesion*

[6] ISO 4618:2006, *Paints and varnishes — Terms and definitions*

[7] ISO 9288:1989, *Thermal insulation — Heat transfer by radiation — Physical quantities and definitions*

[8] ISO 10795:2011, *Space systems — Programme management and quality — Vocabulary*

[9] ISO 11227, *Space systems — Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact*

[10] ISO 16378, *Space systems — Measurements of thermo-optical properties of thermal control materials*

[11] ISO 80000-7, *Quantities and units — Part 7: Light*

[12] JERG-2-310 "Spacecraft thermal control system"

[13] ECSS-Q-ST-70-09C "Space product assurance. Measurements of thermo-optical properties of thermal control materials"

[14] ECSS-ST-Q-70-31C "Space product assurance. Application of paints on space hardware"

[15] ISO/AWI 17851[1)],*Space environment (natural and artificial) — Space environment simulation at material tests — General principles and criteria*

[16] ISO 3668:1998, *Paints and varnishes — Visual comparison of the colour of paints*

[17] ISO 1853, *Conducting and dissipative rubbers, vulcanized or thermoplastic — Measurement of resistivity*

[18] ISO 3915, *Plastics — Measurement of resistivity of conductive plastics*

[19] ISO 15856, *Space systems — Space environment — Simulation guidelines for radiation exposure of non-metallic materials*

[20] ISO 9001, *Quality management systems — Requirements*

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