MEASUREMENT OF SOLAR ABSORPTANCE OF MAP THERMAL-CONTROL COATINGS

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ABSTRACT

Solar absorptance measurements of thermal-control materials PU1, PUK, PNC and SG121FD have been carried out using two methods defined by the ECSS-Q-ST-70-09C [1]. The solar absorptances measured using comparative method (portable device) and spectrophotometer were in the range defined by the technical data sheets of the products. A maximal 0.02 difference was measured between both techniques without any impact on the materials values.
From these measurements, we can assume that both techniques tested on PU1, PUK, PNC and SG1221FD are compliant with the ECSS standard [1].
Using the spectrophotometer technique and benefiting from its higher precision we carried out absorptance measurement versus coating thickness.
We observe very stable solar absorptance for black coatings PU1, PUK and PNC even if the thickness was under or upper the specified thickness of the technical data sheet. On the contrary, solar absorptance of SG121FD decreases continuously from 0.36 to 0.15 by increasing the thickness from 50 to 234 µm. This phenomenon has been attributed to the low hedging power of ZnO treated pigment used in this product for its GEO environment resistance.

Keywords: solar absorptance, thermal-control materials, coatings, space

1 Introduction

Thermal-control materials are used in space to manage the thermal equilibrium of satellites. Thermal-control materials are composed of paints, coatings, Optical Solar Reflectors (OSR), Multiple Layer Insulation (MLI)…
Performance of thermal-control materials is defined through both characteristics: Solar absorptance and Infrared emittance. Solar absorptance is defined as the ratio of the solar radiant flux absorbed by a material (or body) to that incident upon it [1].
Emittance is defined as the ratio of the radiant intensity of the specimen to that emitted by a black body radiator at the same temperature and under the same geometric and wavelength conditions [1].
From the ESA standard ECSS-Q-ST-70-09C [1], two methods can be used to measure the solar absorptance: (1) using a photospectrometer, i.e. based on spectroscopic method or (2) using a comparative method with portable equipment using a xenon flash.
The aim of this paper is to carry out solar absorptance measurements using both methods: photospectrometer and portable equipment in order to compare both methods. In a first part, materials and their application conditions are described, second the devices and the methods used to carry out the measurements are presented. Third, the results are presented for each method and then discussed.

2 Experimental section

2.1 Materials

The materials used for this study were chosen from MAP product range. PU1, PUK, PNC and SG121FD are well-known and largely used thermal-control coatings for satellites.
PU1 and PUK are polyurethane-based black coatings. PU1 is a non-conductive coating whereas PUK is an electrical conductive coating.
PNC is a silicone-based black coating which is electrical conductive. SG121FD is a silicone-based white coating.
The coatings were applied by spray gun pulverization further to their data sheets [2-5]. The polymerization cycle of the coatings was carried out at room temperature, 23 ± 3°C and relative hygrometry of 55 ± 10%.
These coatings were applied on 2017-T4 aluminium alloy flat parts which size is the following: 100 mm x 30 mm x 1 mm.
Several samples were applied varying total thickness of the coating under and upon the specified thickness. Specified thickness is mentioned in Table 1 for each coating.

Coating	Minimal thickness (µm)	Maximal thickness (µm)
PU1	40	80
PUK	40	80
PNC	30	50
SG121FD	100	140

Table 1 Thickness range for PU1, PUK, PNC and SG121FD coatings [2-5]

Moreover the minimal and maximal solar absorptances from the coatings are mentioned in Table 2.

Coating	α_S
PU1	0.96 ± 0.02
PUK	0.97 ± 0.02
PNC	0.98 ± 0.02
SG121FD	0.20 ± 0.02

Table 2 Solar absorptance range for PU1, PUK, PNC and SG121FD coatings [2-5]

2.2 Characterization techniques

2.2.1 Thickness measurement

Thicknesses of the coatings applied on 2017-T4 alloy were measured using a permascope. The principle of measurement is based on the creation of Eddy current in a conductive and non-magnetic material by a probe placed directly on the sample.

2.2.2 Solar absorptance measurement

The solar absorptance (α_s) is the ratio of the solar radiant flux absorbed by a material (or body) to that incident upon it [1].
The solar absorptance can be measured using one the following two methods:

- Portable equipment using a Xenon flash for relative measurements (α_p);
- Spectroscopic method using a photospectrometer covering the range from 0.25 µm up to 2.5 µm for the determination of α_s.

2.2.2.1 Measurement using a portable device

This method is based on comparing the reflection of a Xenon flash by a known appropriate reference material to the reflection of an unknown sample. The nature of the reference material (chemical composition and surface morphology) should be representative for the unknown sample. The solar absorption of the reference surface should be measured using a spectrophotometer.
This method has limitations due to the fact that the flasher spectrum is not identical to the solar spectrum.
The portable reflectometer used in this study is an Elan Informatique EL 511 (Fig.1).

Figure 1 EL511 portable reflectometer

An integrating sphere allows measurement of hemispheric reflectance. A Xenon photographic burst tube provides the light source (300 < λ < 2500 nm). Its spectral distribution is close to solar irradiance (slight difference in the near infrared part). The accuracy of reflectance measurements in absolute value is ± 4%, with reproducibility of ± 1% [6]. The integrating sphere comprises a focusing optics and a detection part by thermopile. The flash of the flash tube is focused on the sample by specific optics. The reflected beam is captured by the reference thermopile, the beam of measurement, gives after calibration with respect to a known solar reflectance sample, the reflectivity value ρ of the sample before the opening of the integrating sphere. The calculation of the absorptance coefficient is done using the formula:

$$\alpha_P = 1 - \rho$$

The use of a flash tube to illuminate the sample provides quick measurements since about 4 measurements can be made in 1 minute [6].
For the solar absorptance measurement of SG121FD, we used a SG121FD witness sample, whereas for PU1, PUK and PNC coatings we used a PSB witness sample. The solar absorptances of the witnesses' samples have been measured at ONERA using a spectrophotometer. The values are mentioned in Table 3.

Witness samples	α_S
SG121FD	0.18
PSB	0.11

Table 3 Solar absorptances for SG121FD and PSB witness samples

2.2.2.2 Measurement using a photospectrometer

Solar absorptance is calculated using the absorption spectrum of the material over the region from 0.25 µm to 2.5 µm and this spectrum is then multiplied with the solar spectrum [7]. The absorption spectrum should be measured using an integrating sphere. For absolute measurements a sphere with central sample mounting should be used. A sphere with a sample holder on the sidewall can also be used. In this case the reflectivity is compared to a known standard (e.g. calibrated Al-mirror or calibrated Spectralon® standard) [8].

The spectrometer used for this study is a PerkinElmer LAMBDA 900R (Fig.2). It allows the measurement of the global, hemispheric reflectance.

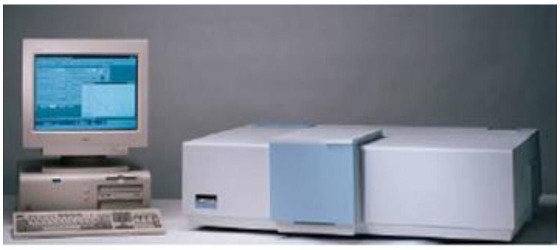

Figure 2 Spectrometer PerkinElmer LAMBDA 900R

This spectrometer allows measurements for the following wavelength range: 185 nm to 3300 nm. The accuracy of the measurement is ± 3% ([9].
The equipment has a halogen tungsten lamp and a deuterium lamp. Bandwidths are 0.05 nm to 5 nm for the UV/VIS range and 0.2 nm to 20 nm for the NIR range.
A sphere of integration with Spectralon coating of diameter 150 mm is used.
The detectors are a high-sensitivity R6872 photomultiplier for the UV/VIS range and a high-performance thermostated PbS cell for the NIR range with automatic switching.
The duration of a measurement is around 10 minutes using this apparatus.

3 Results

3.1 Solar absorptance measurement

3.1.1 Comparative method

The first part of this work was dedicated to the characterization of the solar absorptance using EL511 portable equipment. The etalons used were the following: SG121FD for SG121FD and PSB for PU1, PUK and PNC.

The results based upon the solar absorptance average from 2017 production batches are listed in the Table hereunder.

Coating	α_p	**Standard deviation**
PU1	0.96	0.00
PUK	0.97	0.00
PNC	0.98	0.00
SG121FD	0.20	0.01

Table 4 Solar absorptance average from 2017 production batches measured with portable equipment for PU1, PUK, PNC and SG121FD coatings

Solar absorptances measured with portable device EL511 are compliant to the technical data sheet (Tab.2).

3.1.2 Spectrophotometer

The measurements performed for PU1, PUK and PNC are plotted on the same graph (Fig.3). We can see the evolution of the reflectivity versus wavelength. One can see a smooth curve from 250 nm to 800 nm due to detector used for UV-visible region. For the wavelengths greater than 800 nm corresponding to the IR region, as the detector changed to PbS, the curve is not as smooth as those obtained for the UV-visible region.
For PNC coating, reflectivity is included between 0.02 and 0.04. The integration of the curve in the 250 – 2500 nm area gives a final value for the solar absorptance of 0.97.
Reflectivity of PU1 and PUK is a little bit lower compared to those of PNC. A slight difference is observed under 600 nm, whereas after 600 nm, both PU1 and PUK curves are very close one to each other. The integrated values for 250-2500 nm are respectively 0.95 and 0.96 for PU1 and PUK.

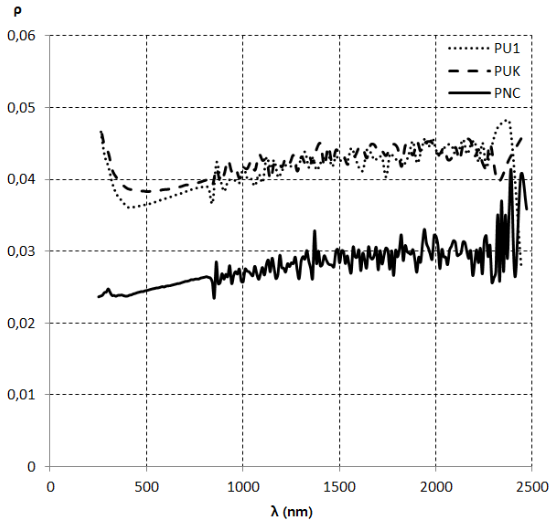

Figure 3 Reflectivity versus wavelength for PU1, PUK and PNC

The reflectivity measurement of SG121FD coating is presented on Fig.4. For the wavelength under 380 nm, reflectivity is close to 0. This white coating has the same behaviour as those of a black coating in this wavelength area. In the 380 – 2500 nm, reflectivity varies a lot from 0.92 to 0.38. The integrated value of the solar absorptance is 0.18.

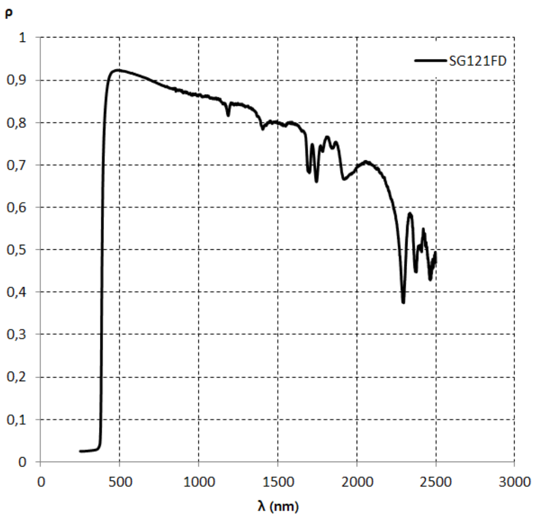

Figure 4 Reflectivity versus wavelength for SG121FD

The results based upon the solar absorptance average from 2017 production batches are listed in the Table hereunder.

Coating	α_S	Standard deviation
PU1	0.96	0.00
PUK	0.97	0.00
PNC	0.97	0.00
SG121FD	0.18	0.00

Table 5 Solar absorptance measured with spectrometer for PU1, PUK, PNC and SG121FD coatings

These results are in good agreement with the technical data sheets of the products, Tab.2 and [10].

3.2 Evolution of solar absorptance versus thickness

Due to the better accuracy of the solar absorptance measurement performed with a photospectrometer, we carried out some measurements varying the thickness of the coatings.
The coatings were applied varying the thickness under and upper the thicknesses specified within the technical data sheet (Tab.1). This work was carried out in order to characterize the global performance of the coating to define the lower thickness required to get a right solar absorptance.
For PU1 coating (Fig.5) we observe a slight increase of the solar absorptance when increasing the thickness. For PUK coating it seems that the behaviour is quite stable in the thickness range of 12 to 100 µm. For PNC coating, if we observe an increase at the low thicknesses (9 to 32 µm), the solar absorptance reaches a stable value and does not increase even if the thickness reaches 100 µm.

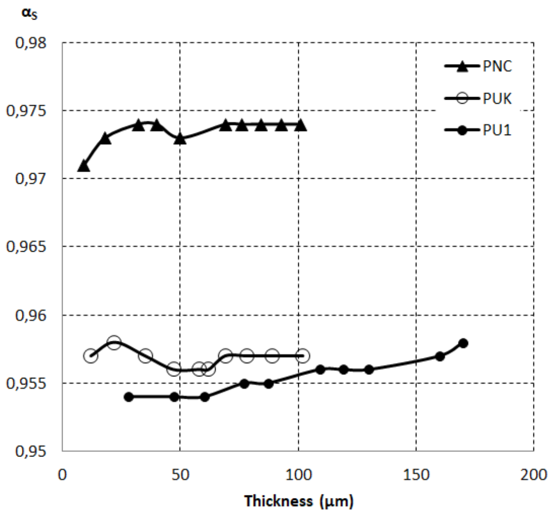

Figure 5 Evolution of solar absorptance of PU1, PUK and PNC versus thickness

For SG121FD coating (Fig.6) we observe a continuous decrease of the solar absorptance from 16 to 234 µm.
For the thickness range specified within the technical data sheet (100-140 µm), the solar absorptance is included in the range 0.17 to 0.19. Reaching a thickness of 100 µm is mandatory to get the right solar absorptance. What could be interesting for specific projects or high-performance needed projects would be to increase the thickness of the SG121FD coating up to 220 µm in order to decrease the solar absorptance to 0.15.

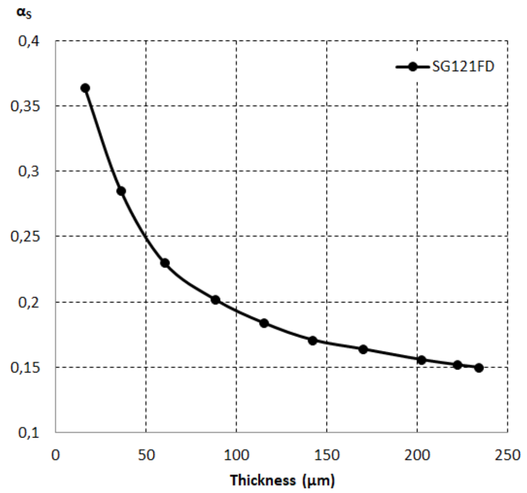

Figure 6 Evolution of solar absorptance of SG121FD versus thickness

In order to define the minimal SG121FD thickness to reach a compliant solar absorptance of 0.18, we applied this coating on PNC (black coating with α_S = 0.97), on 2017-T4 (α_S = 0.18) and on OSR (α_S =0.04). The results are plotted on the graph on Fig.7. For a 50 µm thick SG121FD solar absorptance varies versus the substrate. On 2017-T4 alu-

minium the solar absorptance is 0.25 whereas on OSR, solar absorptance is 0.12 and 0.29 on PNC. These results show that 50 µm thick SG121FD is not enough to reach an opaque coating. Indeed, solar absorptance is influenced by the nature of the substrate. For a 125 µm thick SG121 FD solar absorptances are equal to 0.18 when applied on 2017-T4 alloy and on PNC coating. On the opposite, when applied on OSR, solar absorptance is 0.12.
A thickness of 125 µm is not enough to get the properties of SG121FD [11]. For such a thickness, the influence of the substrate is still obvious. In order to explain such phenomenon, additional tests will be performed.

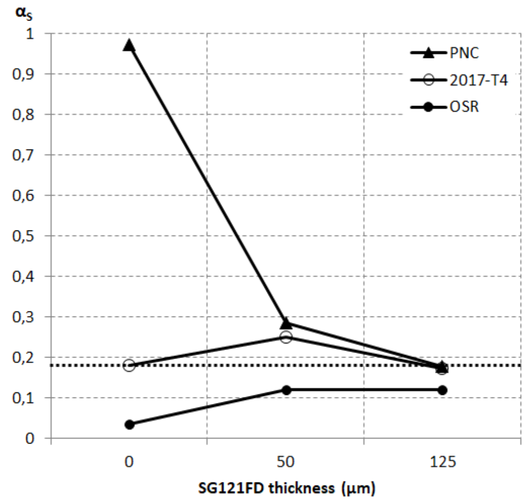

Figure 7 Evolution of SG121FD solar absorptance applied on different substrates

3.3 Comparison of spectrophotometer and comparative method for the solar absorptance measurement

The solar absorptances measured using a spectrophotometer and portable equipment are plotted on the graph of Fig.8 for PU1, PUK and PNC coatings.

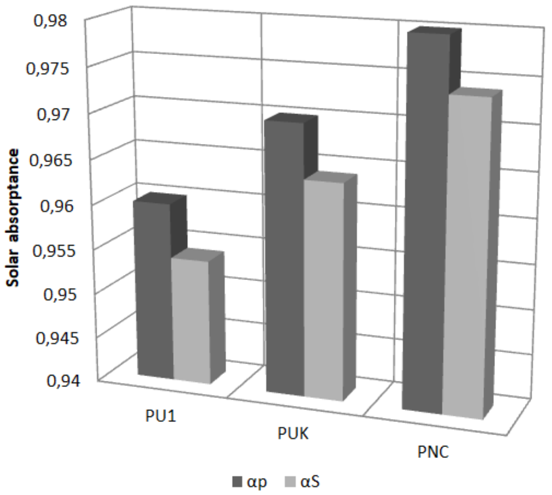

Figure 8 Comparison of solar absorptance measurement using a spectrophotometer and a comparative method (portable device) for PU1, PUK and PNC coatings

These measurements have been carried out for a coating thickness included in the range of the technical data sheet.
We can observe lower values for solar absorptances measured using a spectrophotometer. Difference in the solar absorptance values depending upon the method is in between 0.00 and 0.01.

For SG121FD coating (Fig.9) we obtained quite the same difference: 0.02 with a solar absorptance (α_S) lower than those obtained with the portable device.

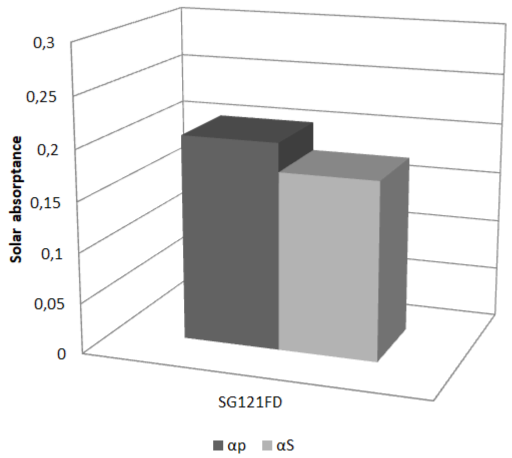

Figure 9 Comparison of solar absorptance measurement using a spectrophotometer and a comparative method (portable device) for SG121FD

We placed in Table 6 the results of solar absorptances measured using a spectrophotometer and a portable device. The difference between α_S and α_P is in between 0.00 and 0.02 depending upon the coating.

	α_P	α_S	**Difference**
PU1	0.96	0.96	0.00
PUK	0.97	0.97	0.00
PNC	0.98	0.97	0.01
SG121FD	0.20	0.18	0.02

Table 6 Comparison of solar absorptance measurement using a spectrophotometer and a comparative method (portable device) for PU1, PUK, PNC and SG121FD coatings

4 Discussion

The solar absorptance measurement versus thickness using a spectrophotometer allows identifying for the black polyurethane coatings PU1 and PUK a large stability of the solar absorptance even if the thickness was out of the specified range: 40-80 µm. For the PNC coating, we observed a slight increase in the solar absorptance for the first 20 µm. Despite this observation, the solar absorptance is of 0.97 even if the thickness is as low as 9 µm.

The global stability of solar absorptance for these black coatings PU1, PUK and PNC can be explained by the very narrow black carbon particles in these formulas which give a very good opacity of the film even at low thicknesses.

On the opposite, we observed a continuous decrease of the solar absorptance of SG121FD in the 16 to 234 µm thickness range. Solar absorptance varies from 0.36 to 0.15. This phenomenon could be explained by the ZnO treated-pigment used in this formula. ZnO is known as one of the best mineral pigment for its behaviour under GEO exposition encountered in space environment. Moreover, hedging power of ZnO is known to be lower than those of TiO_2 for instance. This low hedging power explains that solar absorptance continuously decreases when thickness of the coating increases.

Solar absorptance measured using a spectrophotometer gives values a little bit lower than those measured with portable equipment (0.00 to -0.02).

Measurement performed with portable equipment is a comparative method and for such reason could introduce some differences with an absolute measurement performed using a spectrophotometer.

Moreover, Xenon flash used on portable equipment does not deliver exactly a flux identical to those of the solar spectrum. On the contrary, solar spectrum [7] is used within spectrophotometer. Finally the wavelengths range varies from both methods. Indeed, solar absorptance is integrated between 250 nm and 2500 nm for spectrophotometer whereas integration is carried out only between 300 nm and 2500 nm for portable equipment. If we have a closer look to the spectrum of PU1 and PUK (Fig.3), one can see that on the 250 to 300 nm range, the value of solar absorptance is lower than the average value. By integrating these values in the solar absorptance, global solar absorptance tends to decrease a little bit. For PNC, there is a global stability in the 250-300 nm area. On the contrary for SG121FD, as the solar absorptance is close to 1 in the 250-300 nm area, a higher value of solar absorptance should have been obtained.

Nevertheless, the difference of solar absorptance obtained with both methods is kept under 0.02 and is still compliant with the technical data sheet of all the products.

5 Conclusion

Solar absorptance measurements of thermal-control materials PU1, PUK, PNC and SG121FD have been carried out using two methods defined by the ECSS-Q-ST-70-09C [1]. The solar absorptances measured using comparative method (portable device) and spectrophotometer were in the range defined by the technical data sheets of the products. A maximal 0.02 difference was measured between both techniques without any impact on the materials values. From these measurements, we can assume that both techniques tested on PU1, PUK, PNC and SG1221FD are compliant with the ECSS standard [1].

Using the spectrophotometer technique and benefiting from its higher precision we carried out absorptance measurement versus coating thickness.

We observe very stable solar absorptance for black coatings PU1, PUK and PNC even if the thickness was under or upper the specified thickness of the technical data sheet. On the contrary, solar absorptance of SG121FD decreases continuously from 0.36 to 0.15 by increasing the thickness from 50 to 234 µm. This phenomenon has been attributed to the low hedging power of ZnO treated pigment used in this product for its GEO environment resistance.

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