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BLACK COATINGS FOR COMBINED STRAY LIGHT AND THERMAL PASSIVE MANAGEMENT FOR THE CHALLENGING ENVIRONMENTAL CONDITIONS OF SOLAR ORBITER

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ABSTRACT

In the context of ESA's Cosmic Vision 2015-2025 scientific program, Solar Orbiter (SolO) represents the first M-class mission, currently under implementation for a launch planned in October 2018.
One of the SolO solar remote-sensing instruments is the Multi Element Telescope for Imaging and Spectroscopy (METIS), under development by an Italian consortium ATI composed by CGS and TAS-I. METIS is a coronagraph that will perform simultaneously broad-band imaging in visible light and narrow-band imaging in UV of the Sun corona with unprecedented spatial resolution.
The surfaces of several Ti-6Al-4V components of the METIS Optical Unit must have a very low reflectance in order to minimize straylight and therefore ACKTAR Magic Black™ coating was specified. An example is represented by the internal surface of the Inverted External Occulter (IEO) - the front part of the instrument - which is exposed to the direct solar flux and experiences challenging environmental conditions. Qualification for 450°C was required whereas Acktar's Magic Black™ qualified maximum temperature was 380°C.
A dedicated thermal-vacuum cycling test (100 total cycles, -120°C - 450°C) was conducted to qualify Magic Black™ to quantify any performance degradation under these conditions:

- optical (reflectance)
- thermal (α and ε values) to allow calculation of the radiative heat transfer of the METIS parts during mission
- mechanical performances

The following success criteria were established:

- total reflectance at wavelengths of 400-1000nm <5%
- degradation of absorptance α and emissivity ε to be <10%
- surface resistivity < 5 kΩ/square

Keywords: Solar Orbiter, METIS, stray light, thermal passive management, black coating

1. INTRODUCTION

In the context of ESA's Cosmic Vision 2015-2025 scientific program, Solar Orbiter (SolO, see figure 1) represents the first M-class mission, dedicated to solar and heliospheric physics, currently under implementation for a launch planned in October 2018.[(1)]

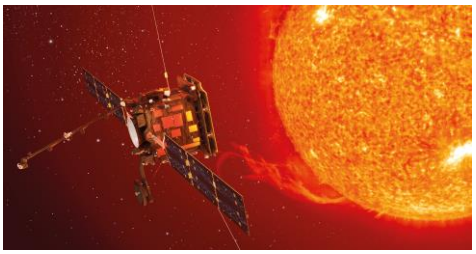

Figure 1. Artist's impression of Solar Orbiter (Credit ESA)

2. METIS OVERVIEW

As one of the six SolO solar remote-sensing instruments (see figure 2), the Multi Element Telescope for Imaging and Spectroscopy (METIS) is proposed by an international scientific consortium led by Istituto Nazionale di Astrofisica (INAF, Astronomical Observatory of Turin), funded by the Italian Space Agency (ASI) and under development and implementation by the Italian consortium ATI composed by Compagnia Generale per lo Spazio (CGS) and Thales Alenia Space – Italia (TAS-I).

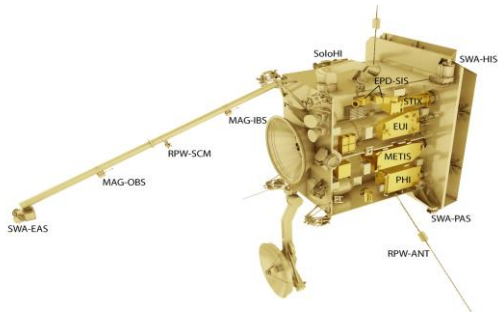

Figure 2. Payload accommodation onboard Solar Orbiter (Credit ESA)

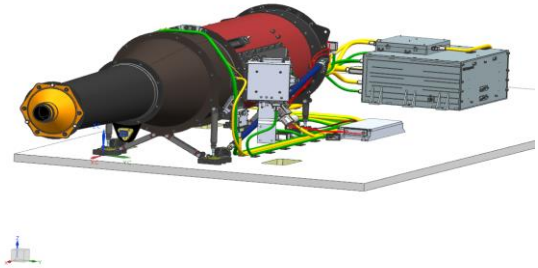

Figure 3. CAD view of METIS (Credit: CGS, ASI)

An example is represented by the METIS Shield Entrance Aperture (SEA), as shown in figure 4.

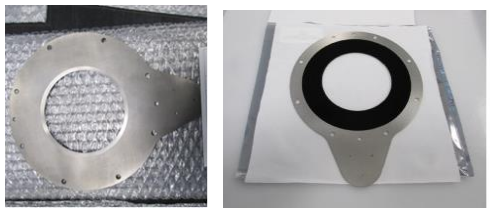

Figure 4. CAD view of the METIS SEA (Credit: TAS-I, ASI)

Magic Black™ is the coating of choice where the absolute lowest reflectance / highest emissivity is required in the FUV – UV ,VIS up to SWIR regions - typically for stray-light suppression. In addition to its superior optical performance (see Figs 5-7). Magic Black™ was thoroughly tested and qualified for thermal cycling, thermal vacuum cycling, cryogenic temperature performance, outgassing, space atomic oxygen and reflectance after environmental exposure.

Magic Black™ delivers many other attributes important in space applications as it has essentially zero outgassing, it is vacuum and thermal-vacuum cycling compatible, suitable for operating temperatures from -269°C to +350°C, has no particulation, it is only a few microns thick and compatible with virtually all substrate materials.
Magic Black™ has been extensively tested and qualified for space applications and is applied in a variety of space programs including among others:

- ESA Bepi Colombo
- Star Trackers on various satellites
- ESA Sentinel 2 – Earth Observation
- Earth Video Camera and more.

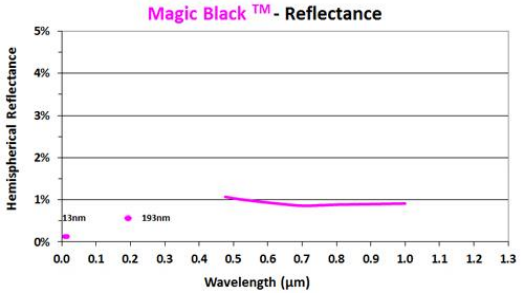

Figure 5. Total Hemispherical Reflectance of Acktar's Magic Black ™ (Credit: Acktar Ltd.) [2]

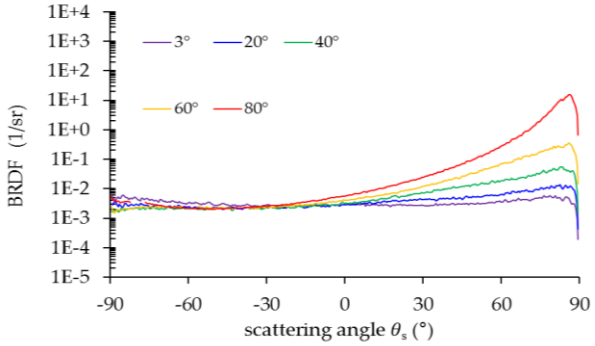

Figure 6. BRDF of Acktar's Magic Black™ at 532 nm wavelength (Credit: Acktar Ltd.) [3]

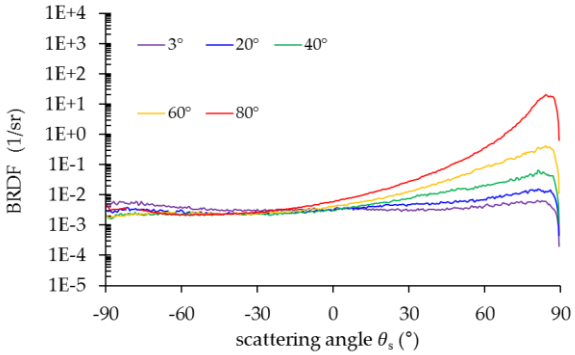

Figure 7. BRDF of Acktar's Magic Black™ at 640 nm wavelength (Credit: Acktar Ltd.) [3]

The METIS Inverted External Occulter (IEO, figure 8) is the front part of the instrument: its surface will be exposed to the solar flux so experiencing very challenging environmental conditions: 380° C was considered as maximum qualification temperature by dedicated thermal analysis conducted by CGS and TAS-I (figure 9). Acktar's Magic Black™ was previously required to be qualified for 350°C as maximum temperature.

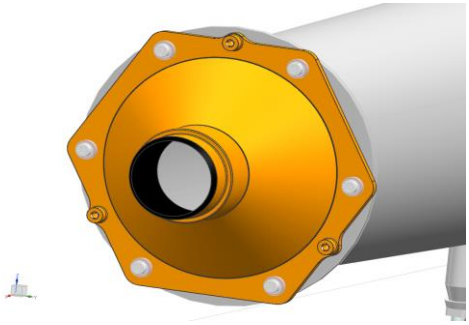

Figure 8. CAD view of the METIS IEO (Credit: CGS, ASI)

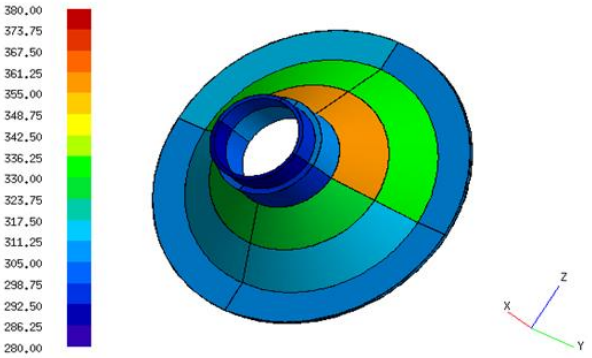

Figure 9. Thermal distribution obtained by thermal analysis on the IEO (Credit: CGS, ASI)

3. QUALIFICATION TEST

A dedicated thermal-vacuum cycling test was planned by CGS, TAS-I and ACKTAR on several titanium coated samples (Figure 10) to qualify the Magic Black™ coating stability up to 380°C.

3.1. Test characterzation

Hereafter the principal features characterizing the test:

- samples material: Ti-6Al-4V
- samples dimensions: 60x60x3 mm
- temperature range: -120°C ÷ 380°C
- total number of cycles: 100
- heating/cooling rate: 10 ± 2 °C/min
- dwell time: ≥ 5 min
- vacuum level: 1×10^{-5} Pa (7.5×10^{-8} Torr)

Figure 10. Coated test sample (Credit: Acktar Ltd.)

3.2. Investigated physical properties

The purpose of the test was to investigate the degradation of the following characteristics:

- optical performances: reflectance
- thermal performances: absorptance α and emittance ε values, by means of which it is possible to correctly calculate radiative heat transfer of the *METIS* parts during mission
- mechanical performances: adhesion test
- surface resistivity
- visual inspection

Figure 11. Surface resistivity test sample (Credit: Acktar Ltd.)

The characterization of the samples was carried out:

- at the beginning;
- after 25 cycles, on a first set of samples;
- at the end (after 100 cycles), on a second set of samples, in order to identify a possible settlement on the investigated physical properties during the cycling test.

3.3. Acceptance criteria

Several acceptance criteria for different characteristics were considered for the test results, as summarized below:

- average reflectivity between 400 and 1000 nm < 2.5%.;
- maximum reflectivity between 580 and 640 nm < 2.5%.;
- α and ε *will* not to degrade by more than 10%;
- surface resistivity to be <5kOhms/square;
- no visible defects shall be observed.

3.4. Test set-up

Thermal Vacuum cycling was conducted using a Test Facility (ITL Inc.) comprising a stainless steel vacuum chamber accommodating a sample holder with a heating/cooling system (figure 12).

The vacuum pumping system consists of an oil-free mechanical scroll pump and a turbomolecular pump with 2,050 l/s pumping speed – capable of achieving the ultimate pressure of $< 10^{-8}$ Torr.
The test samples were placed on the surface of the sample holder plate.

Figure 12. ITL thermal-vacuum chamber (Credit: ITL inc.)

4. CONCLUSION

Acktar Magic black coatings deposited on Ti6Al4V substrates fully meet the thermal-vacuum cycling qualification requirements for the METIS program as they relate to reflectance, absorptance, emittance, adherence, surface resistivity, and visual appearance.

Moreover, due to a IEO hardware design modification, a further thermal-vacuum cycling test will be required to qualify the Acktar™ Magic Black coating up to +450 °C. Further validation of thermo-optical test will be conducted soon on the overall METIS instrument (Thermal Model).

5. REFERENCES

[1] http://sci.esa.int/solar-orbiter/, Instruments, 2015.
[2] Total Hemispherical Reflectance measurements were carried out on black coated items utilizing the Ocean Optics Spectrometer model USB4000 at wavelengths 400-1100 nm.
[3] BRDF measurements were carried out utilizing BRDF measurement systems at the Fraunhofer institute of applied optics and precision engineering (IOF) Jena.