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Durability Testing of a Newly Developed Hydrophilic Anti-Soiling Coating for Solar Reflectors

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Abstract. Anti-soiling coatings for solar reflectors are one of the most useful technical tools to reduce the amount of soiling accumulated on the reflector surfaces, contributing to reduce the water consumption and to increase efficiency in concentrating solar fields. A new anti-soiling coating formulation based on the hydrophilic effect has been recently developed by Tekniker and Rioglass. Reflector samples with this innovative coating were assessed through an accelerated aging test campaign as well as an outdoor exposition at the PSA by CIEMAT and DLR. According to the results obtained, the coating exhibited an appropriate behavior, which implies that the new product represents a promising solution to reduce water consumption.

INTRODUCTION

Water consumption in cleaning tasks of concentrating solar power (CSP) plants is a key issue that is recently being addressed by industry, research institutions and public bodies, not only due to the high cost required to clean the optical surfaces (solar reflectors in all technologies and glass tubes in parabolic-trough collectors) but also due to the water scarcity in many CSP locations [1]. Consequently, minimizing this water consumption is an important aspect for the solar-plant feasibility that must be urgently solved and is currently targeted in several European projects, like WASCOP (EU Horizon 2020, No 654479), MinWater CSP (EU Horizon 2020, No 654443) and SOLWATT (EU Horizon 2020, No 792103).

Several technical solutions have been proposed in this sense, such as dust barriers, anti-soiling coatings for the optical surfaces, low-water consumption cleaning systems and improved methods for the soiling assessment [2]. Among them, anti-soiling coatings deposited on the surface of silvered-glass reflectors are one of the most useful tools that help to mitigate the dust accumulation and consequently reduce the cleaning needs [3]. This solution reduces the water needs and also increases the average reflectance of the solar field along the time. Tekniker and Rioglass have developed an innovative anti-soiling coating for solar reflectors, based on the hydrophilic effect [4]. To be competitive, a proper anti-soiling coating for reflectors must accomplish with the following three requirements:

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1. Negligible reduction of the reflectance properties in the initial status, just after applying the coating and before any possible degradation.
2. Appropriate durability along the time, which means that the coating must keep its optical properties after being exposed to the weather agent.
3. Suitable efficiency regarding the reduction of the dust accumulation under real outdoor conditions.

This paper addresses the behavior of the anti-soiling coating developed by Tekniker and Rioglass under the framework of the WASCOP project, with respect to the two first requirements, according to the experimental campaign performed by CIEMAT and DLR at the PSA. The third one was preliminary presented in [5], where a suitable efficiency was reported, and is also under study in a long-term outdoor test at the PSA. Although this third requirement is out of the scope of this work, it is important to remark that it is the main property expected from an anti-soiling coating product and this is the reason why it is currently under investigation.

METHODOLOGY

Twenty reflector samples were manufactured by Tekniker and Rioglass and sent to the PSA to be tested in the OPAC laboratory (a joint research group between CIEMAT and DLR). All the samples contained an anti-soiling coating layer in the front surface (see Fig. 1). Additionally, some extra samples were manufactured without any coating to be tested as reference material.

FIGURE 1. Picture of one of the reflector samples with anti-soiling coating, manufactured by Tekniker and Rioglass

Initially, all samples were optically characterized to check the reflectance level. The goal of this analysis was to assess the effect of applying the anti-soiling coating in the optical properties of the solar reflector. Optical characterization included visual and microscopic analysis and reflectance measurements. Visual inspection was done to check if the samples possess any obvious macroscopic damages with a Camera LUMIX model DMC-F745 by Panasonic. Then, a microscopic scan of the different layers was conducted with a 3D light microscope model Axio CSM 700 by ZEISS. Reflectance measurements included spectral hemispherical reflectance, $\rho_{\lambda,h}([280,2500],8^{\circ},h)$, as well as monochromatic specular reflectance, $\rho_{\lambda,\varphi}(660\ nm,15^{\circ},12.5\ mrad)$, following the actual SolarPaces reflectance measurement guideline [6]. $\rho_{\lambda,h}$ was measured with a Perkin Elmer Lambda1050 spectrophotometer (see Fig. 2 left), equipped with an integrating sphere of 150 mm diameter, and the data were evaluated with a 2nd surface reference reflectance standard. Three measurements were taken on each sample. The solar-weighted hemispherical reflectance, $\rho_{s,h}([280,2500],8^{\circ},h)$ was calculated using the spectrum given in the ASTM G173-03 standard (direct irradiance, air mass AM 1.5) [7]. $\rho_{\lambda,\varphi}$ was measured with a Devices & Services 15R-USB portable specular reflectometer (see Fig. 2 right). Five measurements were taken, in different points. Also, specularity is presented at 660 nm, $\rho_{\lambda,\varphi}/\rho_{\lambda,h}$.

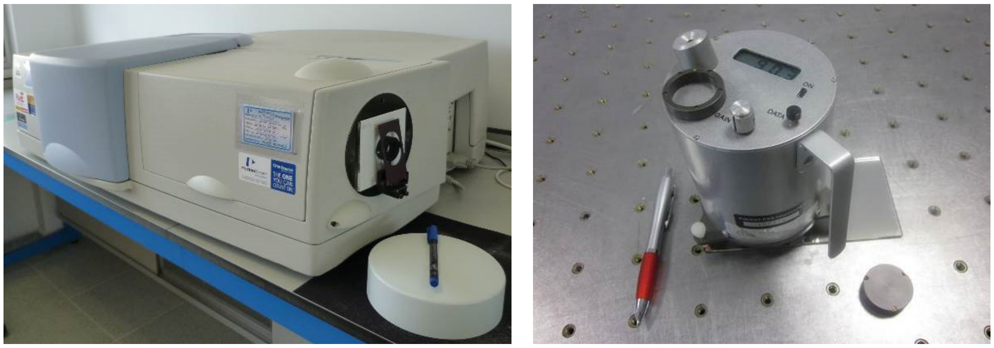

FIGURE 2. Perkin Elmer Lambda 1050 spectrophotometer (left) and D&S 15R-USB reflectometer (right)

The second experimental campaign performed in the PSA-OPAC laboratory to the reflectors samples with anti-soiling coating consisted of applying eight tests in several weathering chambers, and repeating the optical characterization after them, to evaluate the coating durability under accelerated aging. Table 1 summarizes the main parameters of the tests performed. The coated samples were positioned in the weathering chambers (that is, in all tests except the two abrasion ones) with a tilt angle of 20±5° respect to the vertical.

TABLE 1. Main parameters of the accelerated aging tests.

Test	**Samples number / size**	**Time**	**Summary of testing conditions**	**Chamber**	**Standard**
Neutral Salt Spray (NSS)	3/ 150 x 300 x 3 mm^3	480 h	T= 35±2ºC, RH=100%, pH=[6.5,7.2] at 25ºC Sprayed NaCl solution of 50 ± 5 g/l with condensation rate of 1.5 ± 0.5 ml/h on a surface of 80 cm^2	Model 608/ 1000l, by Erichsen	ISO 9227 [8], UNE 206016 [9]
Copper-accelerated acetic acid salt spray (CASS)	3/ 150 x 300 x 3 mm^3	120 h	T=50±2°C, RH=100%, pH=[3.1,3.3] at 25°C Sprayed NaCl solution of 50 ± 5 g/l and 0.26 ± 0.02 g/l $CuCl_2$ Condensation rate of 1.5 ± 0.5 ml/h on a surface of 80 cm^2	Model VSC450, by Vötsch	ISO 9227 [8], UNE 206016 [9]
Condensation (COND)	3/ 150 x 300 x 3 mm^3	480 h	T=40±3°C; RH= 100%	Model CKEST 300l, by Ineltec	ISO 6270-2 CH [10], UNE 206016 [9]
Thermal cycling and humidity (10 TC)	3/ 150 x 300 x 3 mm^3	10 cycles (240 h)	4 h at T=85°C, 4 h at T=-40°C, 16 h at T= 40°C and RH=97±3% (Method A)	Model SC340 MH, by Vötsch	UNE 206016 [9]
Thermal cycling (150 TC)	3/ 150 x 300 x 3 mm^3	150 cycles (≈277 h)	From T=(-40±2)ºC to T= (85±2)ºC. Minimum dwell time 10 minutes within ±3ºC	Model SC340 MH, by Vötsch	IEC 61215 (10.11) [11]
Damp heat (DH)	3/ 150 x 300 x 3 mm^3	1000 h	T=(65±2)ºC; RH=(85±5)%	Model SC340 MH, by Vötsch	IEC 62108 (10.7b) [12]
Abrasion (Taber)	1/ ≈ 60 x 60 x 3 mm^3	100 cycles	Alternative linear movement of an abrasive head (MIL/E/12397) at room temperature	Model 5750, by Taber	ISO 9211-4 [13], UNE 206016 [9]
Abrasion (Washability)	1/ ≈ 60 x 60 x 3 mm^3	200 cycles	Linear movement of a brush head (DIN 53778/B5) back and forth at room conditions under ambient running water	Model 494, by Erichsen	ISO 11998 [14]

Finally, one sample of the same type was outdoor exposed at the PSA for 1.5 years to validate the results achieved in the accelerated aging test campaign. This sample, 300x450 mm^2 size and 4 mm thickness, is half coated and half uncoated and was exposed facing South with 45º inclination. After this period, the sample was cleaned and optically characterized to check any possible degradation.

RESULTS

This section presents all the results obtained in the experimental campaign performed to the reflector samples with the anti-soiling coating developed by Tekniker and Rioglass at the PSA-OPAC laboratory by CIEMAT and DLR.

Initial Optical Characterization

The initial characterization of the samples was used to check the suitability of the coating prior any aging (that is, the requirement number 1 indicated in the introduction section). The results are presented in Table 2, where the three main reflectance parameters are included both for the coated and the uncoated part, as well as the difference between them. According to these results, the standard deviation is quite low in all cases (with maximum values of ±0.002), which indicates a very homogenous behavior on the sample surfaces and among the different samples. If coated and uncoated areas are compared, negligible differences are detected in hemispherical reflectance (values inside the uncertainty of the measurement equipment), and very slight difference is noticed for $\rho_{\lambda,\varphi}$. Accordingly, the specularity at 660 nm was slightly better for the uncoated samples than for the coated ones.

TABLE 2. Average reflectance of the coated and uncoated areas and the difference between them.

Sample	$\rho_{s,h}$	$\rho_{\lambda,h}$	$\rho_{\lambda,\varphi}$	$\rho_{\lambda,\varphi}/\rho_{\lambda,h}$
Coated	0.939±0.002	0.955±0.001	0.950±0.002	0.995±0.002
Uncoated	0.940±0.002	0.956±0.002	0.954±0.001	0.998±0.002
Difference	-0.001±0.003	-0.001±0.002	-0.004±0.002	0.003±0.003

Also, a proportion of samples already presented some defects in the anti-soiling layer (scratches and points) when inspected with the eye and by light microscope (see Fig. 3). These defects are due to the samples preparation dimensions, which are out of the process specification, and will be avoided during the final manufacturing with a clean atmosphere and bigger mirror sizes.

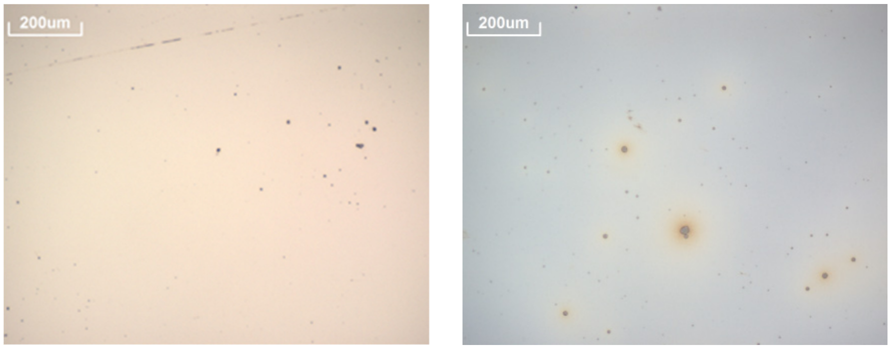

FIGURE 3. Sample microscopic pictures of the coated samples, showing some initial degradation points (scratches and spots) in the top layer (anti-soiling coating)

Accelerated Aging Tests

The accelerated aging test campaign was performed to evaluate the durability of the new anti-soiling coating when submitted to several weathering agents (that is, the second requirement indicated in the introduction section). Table 3 shows the reflectance drop (reflectance after the test minus reflectance before it) after the accelerated aging tests. As it can be seen, the reflectance decrease of the coated samples is negligible for most of the tests, with an average of $\Delta\rho_{s,h} = \Delta\rho_{\lambda,h} = \Delta\rho_{\lambda,\varphi} = -0.001\pm 0.001$. The only exceptions to these negligible values are the neutral salt spray (NSS) and the damp heat (DH) ones, where very slight reflectance decays (-0.003) were noticed. The monochromatic specular reflectance decrease obtained in the NSS test was already reported for non-coated silvered-glass reflectors (with a similar material composition than the one tested in this work) [0] and consequently it is not caused by a degradation of the anti-soiling coating. With respect to the DH test, as no previous results were found in the literature, the experiment was repeated with 3 samples of the same reflector material but without anti-soiling coating. The results of reflectance decay were in the same order and hence it is also considered that the slight degradation was not suffered in the coating layer.

TABLE 3. Average reflectance drop after the accelerated aging tests.

Test	$\Delta\rho_{s,h}$	$\Delta\rho_{\lambda,h}$	$\Delta\rho_{\lambda,\varphi}$
Neutral Salt Spray (NSS)	-0.001±0.001	-0.001±0.000	-0.003±0.003
Copper-accelerated acetic acid salt spray (CASS)	0.000±0.001	-0.001±0.001	0.000±0.001
Condensation (COND)	0.000±0.000	0.000±0.001	-0.001±0.001
Thermal cycling and humidity (10TC)	-0.002±0.000	-0.002±0.001	0.000±0.001
Thermal cycling (150TC)	-0.002±0.000	-0.001±0.001	-0.001±0.001
Damp heat (DH)	-0.003±0.002	-0.002±0.001	-0.003±0.001
Abrasion (Taber)	0.002±0.001	0.001±0.001	-0.001±0.000
Abrasion (Washability)	0.000±0.000	0.000±0.000	-0.001±0.000

Figures 4 and 5 show the hemispherical spectra of the samples, both in the initial state (the average of all the samples) and after the different accelerated aging tests performed. As it can be perceived, no significant decrease was suffered by the samples due to the tests.

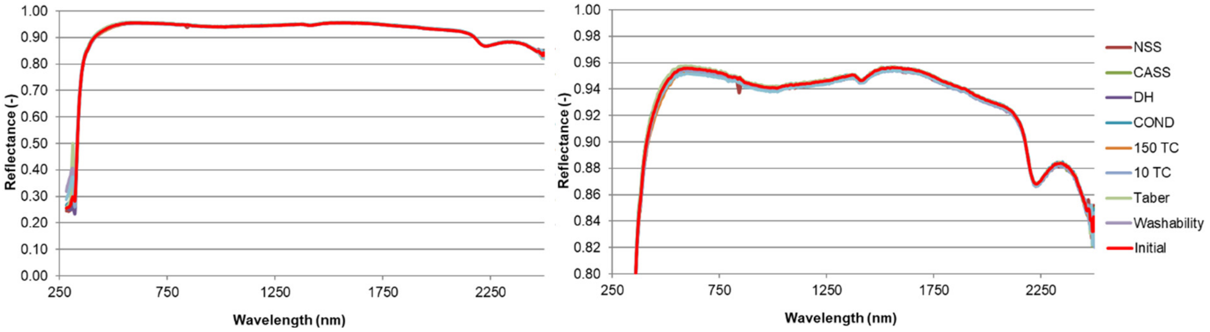

FIGURE 4. Hemispherical reflectance spectra of the coated samples both in the initial state (average) and after all the tests performed, y-axis scale from 0.00 to 1.00 (left) and from 0.80 to 1.00 (right).

In addition, a selection of microscopic pictures is depicted in Fig. 5, to check the possible evolution of some initial defects on the coated layer due to the accelerated aging tests. As it can be perceived, the initial defects did not change their appearance after the tests in all the samples. In addition, no new defects were found in the samples. According to these results, no degradation appeared in the anti-soiling coating layer, even in the NSS and the DH tests, as it was previously suspected.

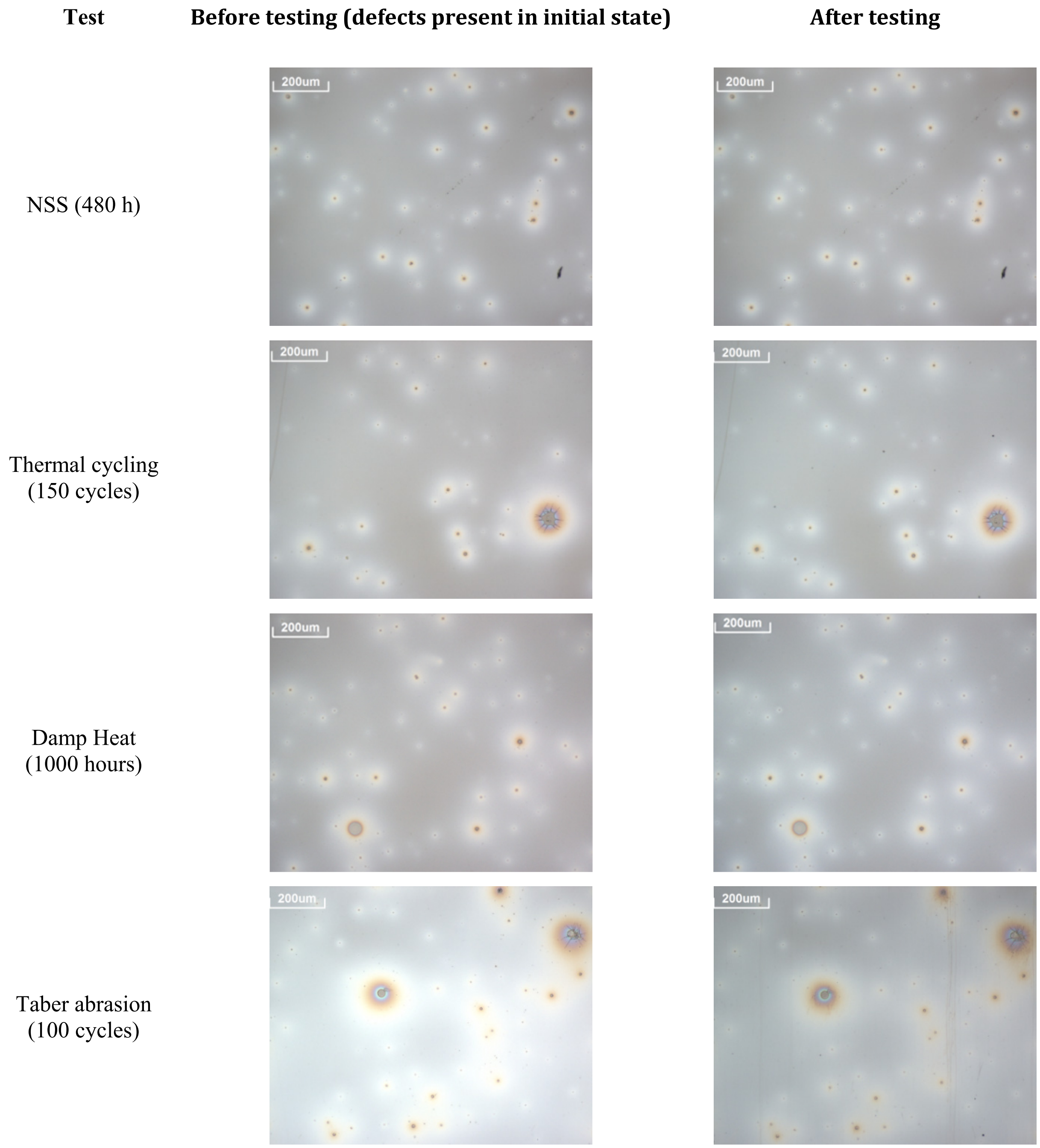

FIGURE 5. Defects in the top layer of several samples before (left) and after (right) 480 h of the NSS test (first row), 150 cycles of the thermal cycling test (second row), 1000 hours of the DH test (third row) and 100 cycles of the abrasion (Taber) test (fourth row)

Finally, Fig. 6 presents some bigger defects that were found in the anti-soiling coating of some samples before any test (due to the reason previously explained). Special attention was paid to these defects because they represent a weak area of the anti-soiling coating, but even in these cases the accelerated aging test did not provoke any evolution of the defects, indicating a high resistance of the coating layer.

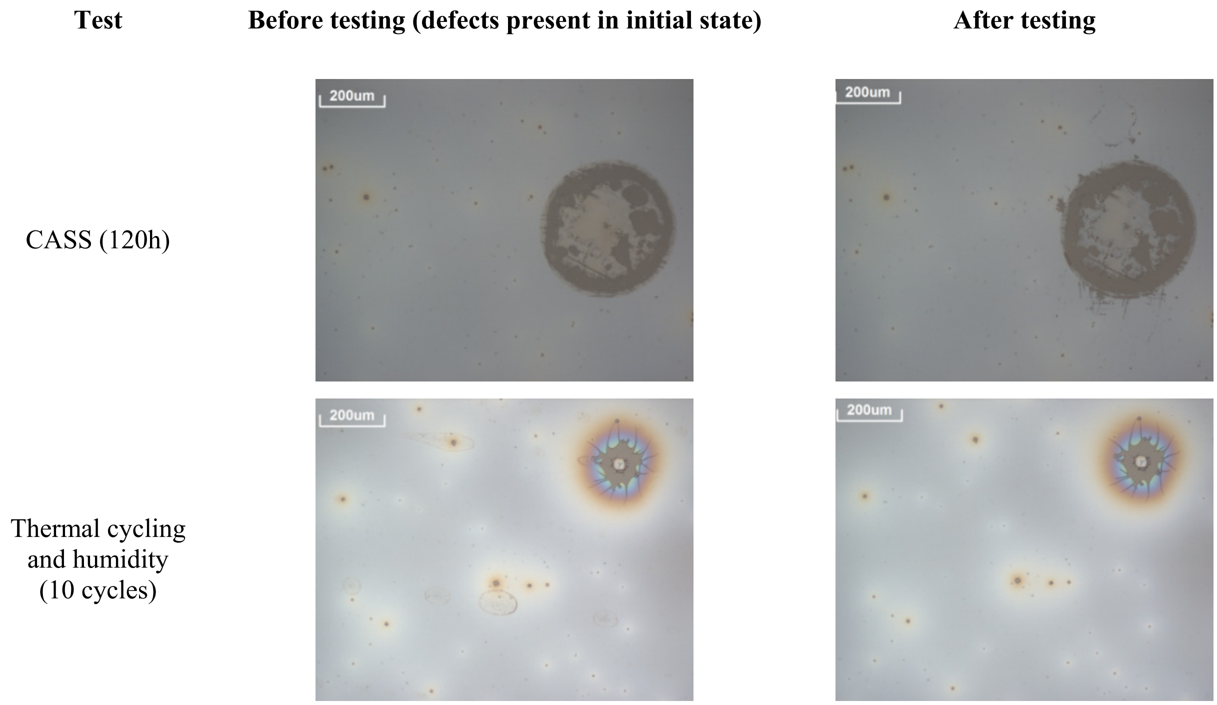

FIGURE 6. Defects in the top layer of several samples before (left) and after (right) 120 h of the CASS test (first row) and 10 cycles of the thermal cycling and humidity test (second row)

Outdoor Test

Finally, the reflectance decay of the sample exposed to outdoor conditions during 1.5 years is indicated in Table 4. As it can be remarked, the reflectance drops found are in the same order of the ones detected during the accelerated aging test campaign.

TABLE 4. Reflectance drop before and after the outdoor exposition at the PSA

	Date	$\rho_{s,h}$	$\rho_{\lambda,h}$	$\rho_{\lambda,\varphi}$
Initial	20/12/2016	0.944±0.001	0.949±0.001	0.959±0.003
After 1.5 years	11/05/2018	0.943±0.000	0.947±0.001	0.956±0.001
Reflectance loss	---	-0.001±0.001	-0.002±0.001	-0.003±0.003

CONCLUSIONS

The durability of the anti-soiling coatings for reflectors developed by Tekniker and Rioglass was checked in the PSA-OPAC laboratory by CIEMAT and DLR. The coating developed does not significantly affect the reflectance of the solar mirror in the initial status with respect to the mirror without coating, with an average of $\Delta\rho_{s,h}= \Delta\rho_{\lambda,h}$ =-0.001 ± 0.003 and $\Delta\rho_{\lambda,\varphi}$ = -0.004 ± 0.002. Regarding the hemispherical and specular reflectance drops due to the accelerated aging tests, almost negligible losses were detected, with maximum values of -0.003 ± 0.003 (in $\Delta\rho_{\lambda,\varphi}$ after the NSS and DH tests and in $\Delta\rho_{s,h}$ after the DH test) and average values of $\Delta\rho_{s,h} = \Delta\rho_{\lambda,h} = \Delta\rho_{\lambda,\varphi}$ = -0.001 ± 0.001. The maximum reflectance losses noticed in the mentioned test are similar to those obtained in this kind of reflectors without any coating, which indicates that the slight degradation is not due to the top layer applied. Also, the initial defects detected on the anti-soiling coating layer of most of the samples (which are due to sample dimensions) do not present any evolution after the accelerated aging tests performed. Finally, the outdoor exposition carried out to one sample of the same type showed reflectance losses in the same range of the ones perceived during the accelerated aging tests, with $\Delta\rho_{s,h} = -0.001 \pm 0.001$, $\Delta\rho_{\lambda,h} = -0.002 \pm 0.001$ and $\Delta\rho_{\lambda,\varphi} = -0.003 \pm 0.003$.

Hence, it has been proven that this coating accomplishes two of the three goals requested for this type of products, that is, the initial reflectance properties are not significantly affected by the coating application and the durability of the coating under the weathering agents considered in this testing campaign is appropriate. The third requirement (anti-soiling effect) is under evaluation in a long term on-site test, to prove the appropriateness of the coating in fulfilling the main goal of this kind of products.

In addition, more severe accelerated aging tests are recommended in further investigations to check the suitability of the coating developed in more aggressive conditions. In most of the cases, the conditions of the above exposed tests have been set according to the current standard testing methods commonly accepted by the industry. Nevertheless, the researchers are planning to go further and to develop a new protocol including more severe tests to assess suitability of the new coating even in the more aggressive conditions.

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