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► **To cite this version:**

Anne-Claire Pescheux, Olivier Raccurt, Delphine Bourdon, Estelle Le Baron. Accelerated aging tests and characterizations of innovated anti-soiling coatings for solar receiver glasses. *Materials Chemistry and Physics*, 2020, 256, pp.123646. <10.1016/j.matchemphys.2020.123646>. <hal-03491448>

HAL Id: hal-03491448

<https://hal.science/hal-03491448v1>

Submitted on 30 Aug 2022

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Accelerated Aging Tests and Characterizations of Innovated Anti-soiling Coatings for Solar Receiver Glasses

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Abstract. Durability tests of solar materials are crucial to guarantee the profitability of the Concentrated Solar Power (CSP) plants and to ensure a proper efficiency during their lifetime. As solar mirrors and absorbers, optical performances of receiver glasses are affected by soiling phenomenon and surface degradations, especially in desert and coastal environments. Indeed, the deposition of dust particles, salts, organic materials or any other contaminants present in the solar field or around the CSP installation sites can generate an important optical loss. Some coatings have been developed by a manufacturer to avoid the deposition of a soiling layer on the glass surface and to keep good optical performances. Their formulations are confidential but this paper presents the results and the comparison of the four different anti-soiling coatings, deposited on glass substrates and subjected to several accelerated aging tests. The conclusion of this work will help the manufacturer to make a choice about the most durable coating for industrialization.

Keywords. CSP plants, Receiver glass, Anti-soiling coating, Accelerated aging test, Transmittance, Contact angle

Nomenclature

$\tau(\lambda)$	Normal hemispherical transmittance, in percentage (%)
I_{sample}	Measured detector intensity with samples
I_{air}	Measured baseline intensity in air
<i>Zeroline</i>	Baseline recorded in order to correct the measurements from noise
τ (SW)	Solar weighted transmittance, in percentage (%)
$\tau(\lambda_i)$	Spectral transmittance, in percentage (%)
E_{dir}	Solar direct irradiance on the Earth surface, in Watt per square meter ($W.m^{-2}$)
λ	Wavelength, in nanometer (nm)
θ_c	Contact angle, in degree (°)
γ_{sv}	Solid-vapor interfacial energy, in Newton per meter ($N.m^{-1}$)
γ_{sl}	Solid-liquid interfacial energy, in Newton per meter ($N.m^{-1}$)
γ_{lv}	Liquid-vapor interfacial energy, in Newton per meter ($N.m^{-1}$)
κ	Line tension, in Newton [N]
α	Droplet radius, in meter [m]

1. Introduction

Solar energy is a renewable and carbon dioxide-free way to produce energy. Concentrated Solar Power (CSP) plants have been developed to generate and store heat during the day, in order to transform it into electricity. To be efficient, this technology requires a high level of direct normal radiation (DNI). According to the Köppen-Geiger climate classification [1] and the CSP map established by the Deutsches Zentrum für Luft- und Raumfahrt (DLR), most of the solar power plants are situated in desert or coastal area [2]. However, these environments are subjected to aggressive stress factors as high temperature, humidity, UV radiation, or saline mist, which can degrade the solar components like mirrors, absorbers and receiver glasses [3][4][5]. That is why durability testing of components is a crucial aspect to guarantee the profitability of the plants and to ensure a proper efficiency during their lifetime estimated at approximately 25 to 30 years [6][7]. To save time, outdoor conditions have been simulated in climatic chambers where solar materials have been tested in an accelerated manner during a few weeks [8][9][10].

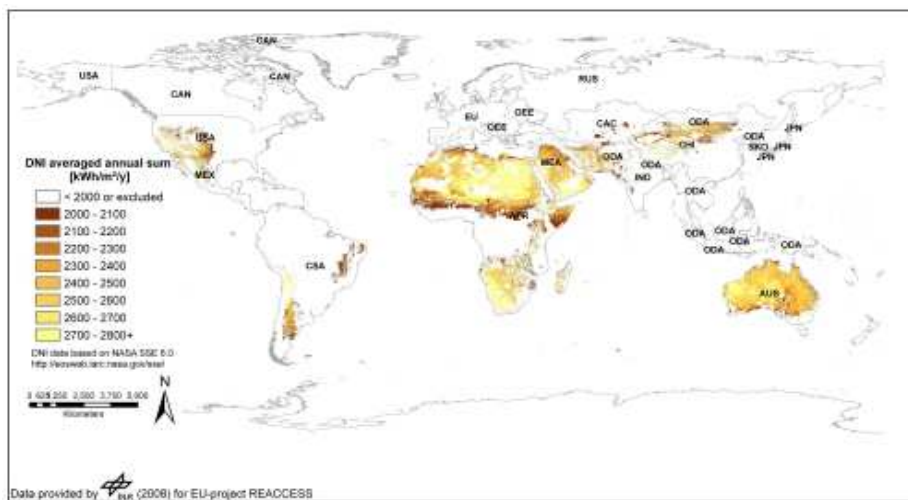


FIGURE 1. Map of potential locations for CSP plants [2]

Nowadays, the goal for the industrials is to minimize the cost of energy, of maintenance and the environmental impact of solar materials [11]. Indeed, solar compounds are often soiled and have to be cleaned regularly [12][13]. In order to improve water saving in the cleaning activities of CSP plants, one main specific objective is to reduce the cleaning needs. In the framework of the WASCOP project [14], experimental anti-soiling coatings have been selected, able to satisfy specific solar receiver glasses requirements, as solar transmittance ($< 92\%$) and high hydrophobicity ($< 30^\circ$). We performed accelerated aging tests in order to evaluate their properties regarding degradation (strength of the thin film, corrosion, cracks, bubbles ...) and performance (better transmittance and higher contact angle values than without coating).

This work presents the results of these tests and concludes with the selection of the less affected by aging anti-soiling coating, which will undergo on-site outdoor testing before being industrialized.

2. Experimental

2.1. Samples

The samples of this study, provided by a project partner, are commercialized pieces of glass used to protect receiver tubes in CSP plants. They have a size of 60 mm x 60 mm and a thickness of 3 mm. Four different anti-soiling coatings, one commercialized and three new formulations have been deposited on the glass surface by dip-coating process [15]. These thin films, called A (commercial reference), B, C and D in this paper, look different whether their color or their texture. The goal of these new coatings is to reduce soiling on the glass surface thanks to

a hydrophobic sol-gel solution composed by SiO₂ nanoparticles with 2 different thicknesses (thin for samples B and thick for samples C) and TiO₂ nanoparticles (samples D). The contact angle of these coatings are higher than the uncoated glasses (<30°) and they also show a better transmittance (<92%). Finally, the films allow to protect the glass of the corrosion and minimize the soiling rate.

Three samples of every coatings are subjected to each accelerated aging test. Before any measurements, eventual dust is removed by filtered pressurized air. A series of measurements are made at different spots on the sample, at initial and final testing time. The mean values and standard deviations are presented in the results of this paper.

2.2. Accelerated aging tests

In this study, all the samples are subjected to five accelerated aging tests, summarized in the Table 1. These tests allow to verify the durability of the anti-soiling coatings deposited on the glass surface of the solar receivers, according to different climatic stress factors (saline mist, high temperature and humidity, UV radiation and rain) to replicate the weather conditions in different regions of the world. Some of them are standardized and already used in other CSP projects, especially for studying the durability of the solar reflectors [16]. The other tests are not standardized yet but are used for several years in the studies of our laboratory according to the climatic parameters on our experimental solar platform in Cadarache (France).

Test	Manufacturer	Model	Standard	Testing time
NSS	Weiss	SC 450	ISO 9227	3000 h
Damp Heat	Climacell	111	IEC 62108 10.7b	2000 h
Xenon radiation with water spray	Atlas	Suntest XXL+	ISO 16474-2	2000 h
Constant temperature	Nabertherm	NAC 250/45	-	1500 h
UV-5X	BIA Climatic	UV5X	-	1600 h

TABLE 1. Summary of the accelerated aging tests

2.2.1. NSS test

The Neutral Salt Spray (NSS) test, according to ISO 9227 [17], is a widely used corrosion test to simulate coastal environments. Samples are exposed to constant conditions of 35°C with a spray of a NaCl solution (50 ± 5 g/L, pH=6.5-7.2) at 100% humidity. The samples are positioned with a tilt angle of 20 ± 5° respect to the vertical within the salt spray chamber with the coated surface upwards. The amount of the sprayed solution is adjusted to obtain a condensation rate of 1.5 ± 0.5 mL/h on a surface of 80 cm². The test was carried out in a chamber from the company Weiss during 3000 hours.

2.2.2. Damp Heat test

The Damp Heat test, according to the IEC 62108 10.7b [18], consists in exposing the samples to a constant climate of 65 ± 2°C and 85 ± 5% of relative humidity to simulate equatorial regions. Samples are positioned in the chamber with an inclination of around 25° to the vertical, front side up. The test was carried out in a chamber from the company Climacell during 2000 hours.

2.2.3. Xenon radiation with water spray test

The Xenon radiation with water spray test, according to ISO 16474-2 [19], allows to simulate a sunny day with a few showers. It consists of the following cycle: in the beginning, samples are exposed to a water spray during 3 min. Afterwards, samples are exposed during 27 min to a xenon radiation (irradiation xenon lamp with filter, 65 W/m² between 300-400 nm). The total duration of one cycle is 30 min. Samples are tested with the coated side facing

towards the chamber interior. The test was carried out in a chamber from the company Atlas during 4000 cycles (or 2000 hours).

2.2.4. Constant temperature test

The constant temperature test has not a specific standard yet. It consists in heating the samples at constant high temperatures to simulate the temperature of glass surface received in a CSP plant. Samples are positioned in the chamber with an inclination of around 25° to the vertical, front side up. For this study, three different temperatures were chosen: 200°C, 250°C and 300°C. The test was carried out in three chambers from the company Nabertherm during 1500 hours.

2.2.5. UV-5X test

The UV-5X test has not a specific standard yet. It consists in exposing the samples to a high UV radiation dose (5 times solar). The ambient temperature inside the chamber is monitored at 70°C and the relative humidity is not controlled. Samples are positioned in the chamber in front of the light source (xenon lamp + filter, 200 W/m² between 300-400 nm). The test was carried out in a chamber from the company BIA Climatic during 1600 hours.

2.3. Characterizations

In this study, all the samples are measured by two ways. The normal hemispherical transmittance is measured by a spectrophotometer and allowed to detect an eventual loss of transparency of the glass. The contact angle is measured thanks to a goniometer to verify the hydrophobicity of the anti-soiling coating. These characterizations, summarized in the Table 2, have been made at the beginning and at the end of the accelerated aging tests on each sample, in order to detect a potential degradation on the coatings.

Characterization	Instrument	Manufacturer	Model	Accessory
Transmittance	Spectrophotometer	Perkin Elmer	Lambda 950	Integrating Sphere (Ø 150 mm)
Contact angle	Goniometer	Krüss	DSA 25	-

TABLE 2. Summary of the measurement equipments

In this study, 60 samples have been tested (3 samples x 4 coatings x 5 accelerated aging tests). All the coatings have been measured with both equipments. We obtained 120 data points (2 x 60 samples) for the transmittance measurements and 180 data points (3 x 60 samples) for the contact angle measurements.

2.3.1. Transmittance measurement

Normal hemispherical transmittance [20] is measured with a setup consisting of a Perkin Elmer Lambda 950 spectrophotometer, with an integrating sphere of 150 mm diameter in the solar wavelength range [280 – 2500 nm] and a resolution of 5 nm. The incidence beam (7mm x 17mm) is perpendicular to a tangential plane touching the sample area of measurement. Baseline measurement of air is used in the evaluation as a reference for 100% transmittance and the sample transmittance is calculated using the Equation (1), where I_{sample} denotes the measured detector intensity with samples and I_{air} is the measured baseline intensity in air. Prior to the measurements, a *Zeroline* has been recorded in order to correct the measurements from noise.

$$\tau(\lambda) = \frac{I_{sample}(\lambda) - Zeroline(\lambda)}{I_{air}(\lambda) - Zeroline(\lambda)} \quad (1)$$

Following ASTM Standard E903-96 [21], the solar weighted transmittance τ (SW), can be calculated by weighting the spectral transmittance $\tau(\lambda_i)$ with the solar direct irradiance on the Earth surface for each wavelength λ_i (E_{dir,λ_i}), according to the Equation (2). For European and North America latitudes, typical solar irradiance spectra are given by the current standard norms ASTM G173-03 [22].

$$\tau(SW) = \frac{\sum_{i=1}^n \tau(\lambda_i) \cdot E_{dir,\lambda_i} \cdot \Delta\lambda_i}{\sum_{i=1}^n E_{dir,\lambda_i} \cdot \Delta\lambda_i} \quad (2)$$

Each coated sample is measured twice on its center. The average and the standard deviation are then calculated.

2.3.2. Contact angle measurement

The static sessile drop contact angle [23] is measured by a contact angle Krüss DSA25 goniometer using an optical subsystem to capture the profile of a pure liquid on a solid substrate. The theoretical description of contact arises from the consideration of a thermodynamic equilibrium between the three phases: the liquid phase L, the solid phase S and the vapor phase V [24]. This equilibrium is presented in the Equation (3), where γ_{SV} is the solid-vapor interfacial energy [$N \cdot m^{-1}$], γ_{SL} the solid-liquid interfacial energy [$N \cdot m^{-1}$], γ_{LV} the liquid-vapor interfacial energy [$N \cdot m^{-1}$] and θ_C the equilibrium contact angle [$^\circ$].

$$\gamma_{SV} - \gamma_{SL} - \gamma_{LV} \cos\theta_C = 0 \quad (3)$$

The value of the contact angle is calculated via an internal device using the Young-Dupré method thanks to the software EasyDrop. This method uses the Equation (4) where κ is the line tension [N] and α is the droplet radius [m].

$$\cos\theta_C = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}} + \frac{\kappa}{\gamma_{LV} \alpha} \quad (4)$$

Measurements are taken every 10 seconds on a deionized water droplet of $5\mu L$ and the average value is calculated. Moreover, three drops are deposited on the glass surface to see the homogeneity of the coating. The average and the standard deviation of these three droplets are calculated.

3. Results

3.1. Initial characterizations

Before each test, every sample have been carefully cleaned and initially measured with the spectrophotometer and the goniometer to obtain reference measurements. For both equipments, Figure 2 indicates the average values for uncoated (in green) and coated glass samples (in red). The uncoated glass taken as reference in this study shows a transmittance of 92% and a contact angle of 30° . It can be noticed that the anti-soiling coatings improve the optical properties of the absorber glasses (around +3.5% for transmittance and around +32.5° for contact angle). The values obtained for the solar weighted transmittance at initial time show an average of $95.4 \pm 0.9 \%$ while the values obtained for the contact angle at initial time show an average of $62.5 \pm 10.6^\circ$. We can see a large dispersion of the results and therefore a non-homogeneous set of samples, certainly due to a non-repetitive preparation. Indeed, a lot of coated samples have been prepared over several days, by different operators, with a different size of the coated surface, a different drying time, and have been send into several packages.

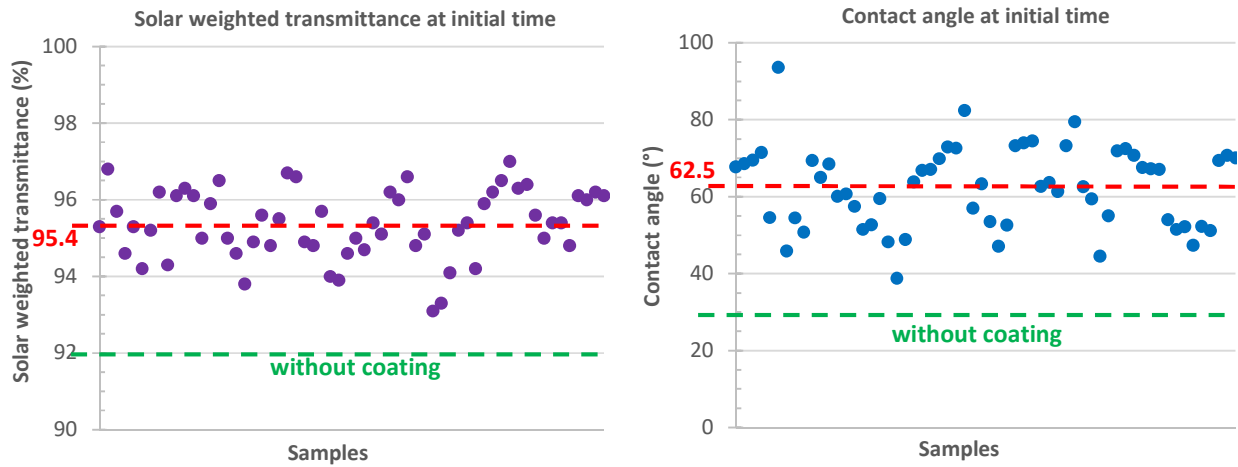


FIGURE 2. Initial characterizations of every samples before being tested

Then, three samples of every coatings are positioned in the climatic chambers during 1500 to 3000 hours. At the end of the different tests, samples have been measured again with both equipments to obtain final measurements. For every coating, an average of the three values has been calculated.

In this paper, the measurements obtained at $t=0$ are not really important and it would even complicate the comparison of the results. Only the differences between the initial and final values obtained for both characterizations are presented in the following tables and figures. These differences allow to see in a better way the loss or the gain of the optical performances of the coatings after the accelerated aging tests, that is the real goal of this study.

3.2. NSS test

Table 3 shows a summary of the solar weighted transmittance and the contact angle differences after the NSS test for the four coatings. A transmittance loss between 0.5 to 2% was detected after 3000h. This loss is the most important for the coatings A and D. Also, the slight difference of contact angle for the coatings B and C can be considered as negligible. On the contrary, this difference is much larger for the coatings A and D with a loss higher than 20° . Regarding the optical microscope images in Figure 3, the salt solution has started to remove the thin films, represented by dark and light areas on the pictures, reducing their anti-soiling performances on the entire surface. In conclusion, the two most resistant coatings to this accelerated aging test are the coatings B and C.

Coating	$\Delta\tau_{(sw)}$ (%)	$\Delta\theta_c$ ($^\circ$)
A	-1.5 ± 0.4	-26.4 ± 11.2
B	-0.5 ± 0.4	-4.5 ± 21.7
C	-1.1 ± 0.4	-4.3 ± 11.1
D	-2.0 ± 0.4	-20.2 ± 8.8

TABLE 3. Summary of the results after the NSS test (3000h)

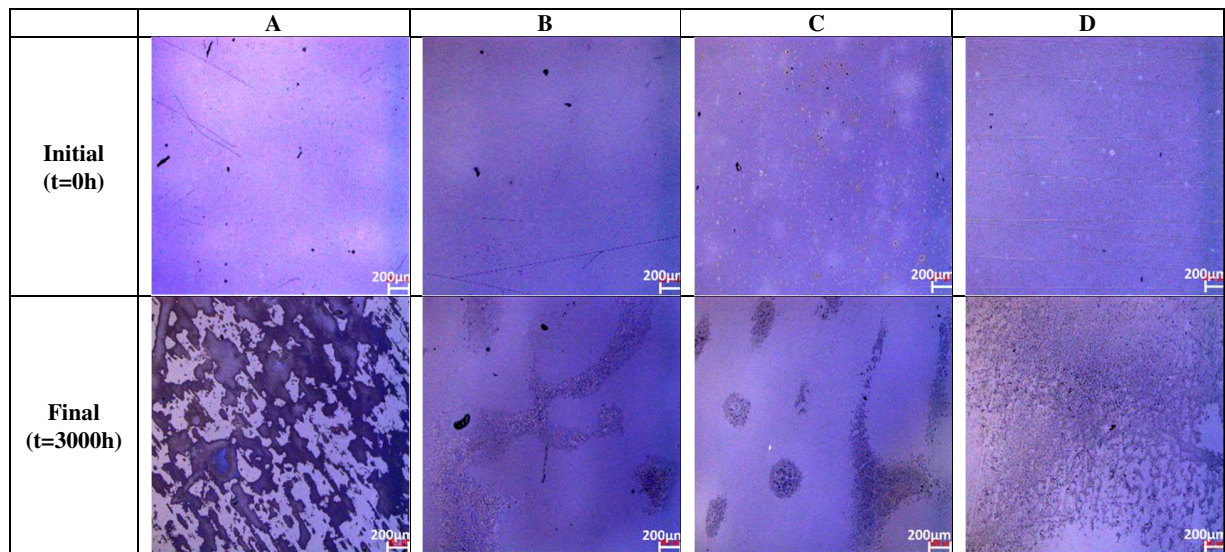


FIGURE 3. Optical microscope images of the four coatings before and after the NSS test (3000h)
Zoom: X10 / Scale: 200 µm

3.3. Damp Heat test

Table 4 shows a summary of the transmittance and the contact angle differences after the Damp Heat test for the four coatings. Concerning the transmittance results, a loss between 0.4 to 2.6% was detected after 1500h. This loss is the most important for the coatings A and D, and almost negligible for the coating B. On the contrary, the hydrophobic character of the thin films have been improved on every samples with an increase of the contact angle between 10.5 to 30.3°. This effect could be due to the temperature inside the chamber (~65°C) which probably improves the stability of the coatings and then their performances. This hypothesis will be verified in a complementary study with infrared measurements, which could prove a densification of the sol-gel layers thanks to the creation of chemical bonds and the water loss as by-product of condensation. Regarding the optical microscope images in Figure 4, some bubbles have been appeared after 1500h on every coatings because of the temperature of the test. In conclusion, the two most resistant coatings to this accelerated aging test are the coatings B and C.

Coating	$\Delta\tau_{(sw)}$ (%)	$\Delta\theta_c$ (°)
A	- 2.1 ± 0.2	+ 18.5 ± 2.6
B	- 0.4 ± 0.2	+ 25.5 ± 6.8
C	- 1.2 ± 0.1	+ 30.3 ± 4.1
D	- 2.6 ± 0.3	+ 10.5 ± 3.0

TABLE 4. Summary of the results after the Damp Heat test (1500h)

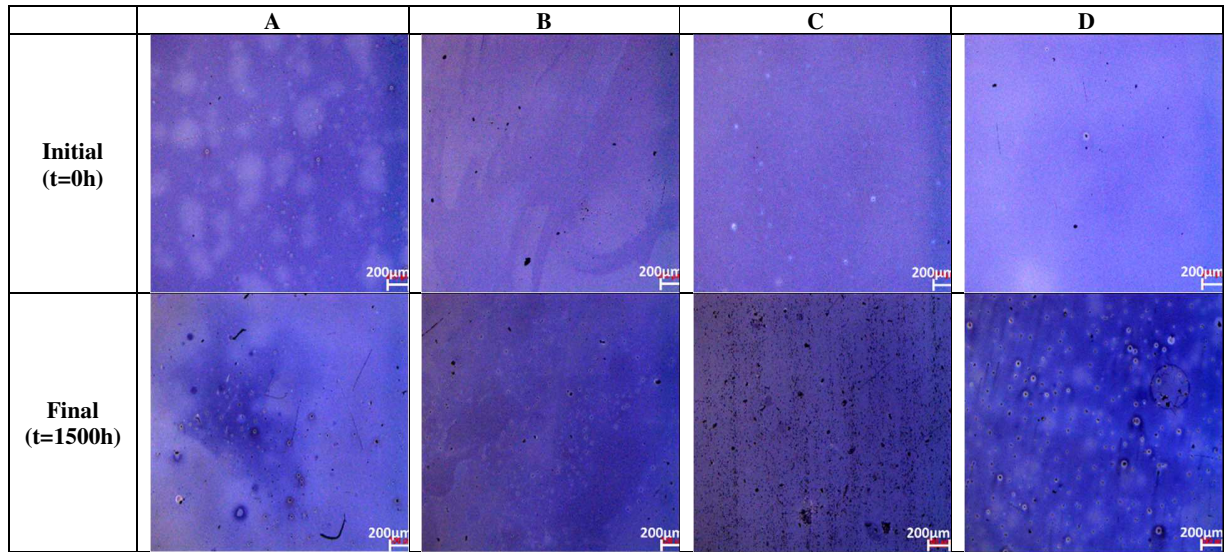


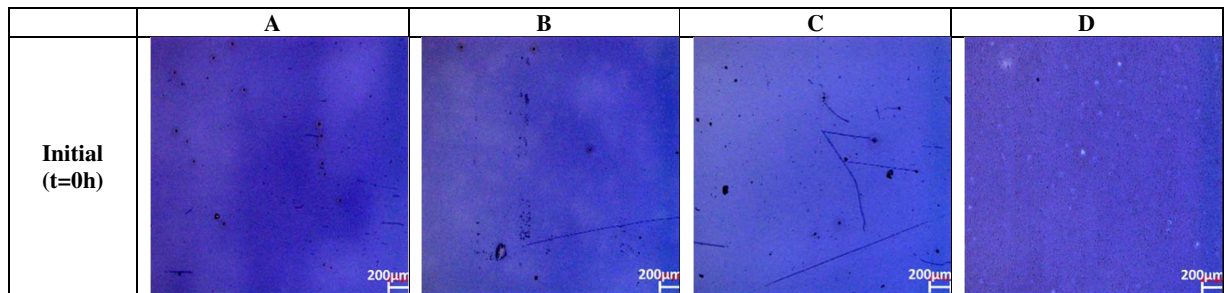
FIGURE 4. Optical microscope images of the four coatings before and after the Damp Heat test (1500h)
Zoom: X10 / Scale: 200 µm

3.4. Xenon radiation with water spray test

Table 5 shows a summary of the transmittance and the contact angle differences after the Xenon radiation with water spray test for the four coatings. Concerning the transmittance results, samples with the coatings B and C showed a slight decrease of 0.4 to 0.7% after 2000h while the two other showed a loss of 1.1 to 1.2%. The contact angle results revealed an important loss of the hydrophobic character for all the samples between 9.8 to 34.6%. Regarding the visual inspection after 2000h in Figure 5, a lot of cracks appeared on every samples because of the thermal shock due to UV and water. These surface defects could explain the loss of transmittance and contact angle. In conclusion, the two most resistant coatings to this accelerated aging test are the coatings B and C.

Coating	$\Delta\tau_{(sw)}$ (%)	$\Delta\theta_c$ (°)
A	- 1.1 ± 0.7	- 28.2 ± 5.5
B	- 0.4 ± 1.0	- 23.2 ± 10.0
C	- 0.7 ± 0.5	- 9.8 ± 10.4
D	- 1.2 ± 0.2	- 34.6 ± 5.7

TABLE 5. Summary of the results after the Xenon radiation with water spray test (2000h)



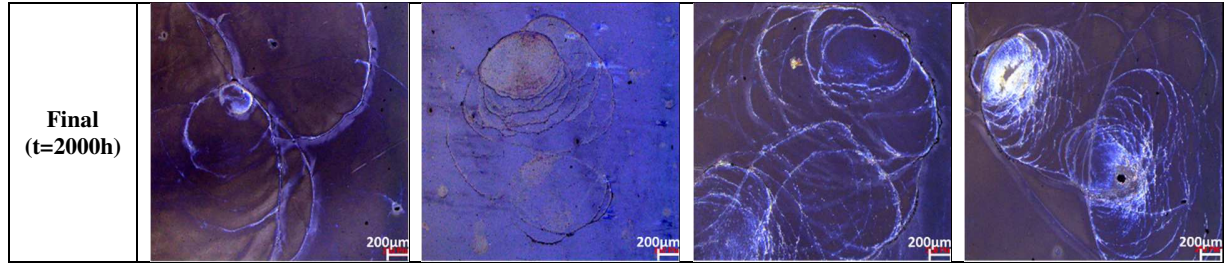


FIGURE 5. Optical microscope images of the four coatings before and after the Xenon radiation with water spray test (2000h)
Zoom: X10 / Scale: 200 µm

3.5. Constant temperature test

Table 6 shows a summary of the transmittance and the contact angle differences after the Constant temperature test for the four coatings. At first sight, it can be revealed that the lower the temperature is, the higher the transmittance is. There is a gain of transmittance between 0.1 to 2.2% after 1500h which could be due to the temperature of this test. Indeed, a high temperature tends to improve the stability of the coatings and then their optical performances. On the other hand, the higher the temperature is, the lower contact angle is. An important loss between 10.0 to 64.3° was detected at the end of the test according to the temperature. This could be explained by regarding the visual inspection in Figure 6. We can notice that all the samples present a lot of bubbles on their coating and some lighter spots after 1500h. The higher the temperature is, the more bubbles there are. In conclusion, the two most resistant coatings to this accelerated aging test are the coatings B and C.

Coating	Temperature (°C)	$\Delta\tau_{(sw)}$ (%)	$\Delta\theta_c$ (°)
A	200	+ 0.7 ± 0.0	- 23.4 ± 2.1
	250	+ 0.4 ± 0.1	- 30.1 ± 3.0
	300	+ 0.1 ± 0.2	- 54.0 ± 2.9
B	200	+ 1.7 ± 0.2	- 14.3 ± 5.7
	250	+ 1.0 ± 0.2	- 16.0 ± 4.0
	300	+ 0.6 ± 0.1	- 43.3 ± 4.0
C	200	+ 2.2 ± 0.2	- 10.0 ± 2.5
	250	+ 1.6 ± 0.2	- 14.9 ± 3.1
	300	+ 1.2 ± 0.1	- 40.3 ± 4.6
D	200	+ 1.1 ± 0.2	- 26.6 ± 4.2
	250	+ 1.0 ± 0.1	- 32.4 ± 3.0
	300	+ 0.7 ± 0.0	- 64.3 ± 3.0

TABLE 6. Summary of the results after the Constant temperature test (1500h)

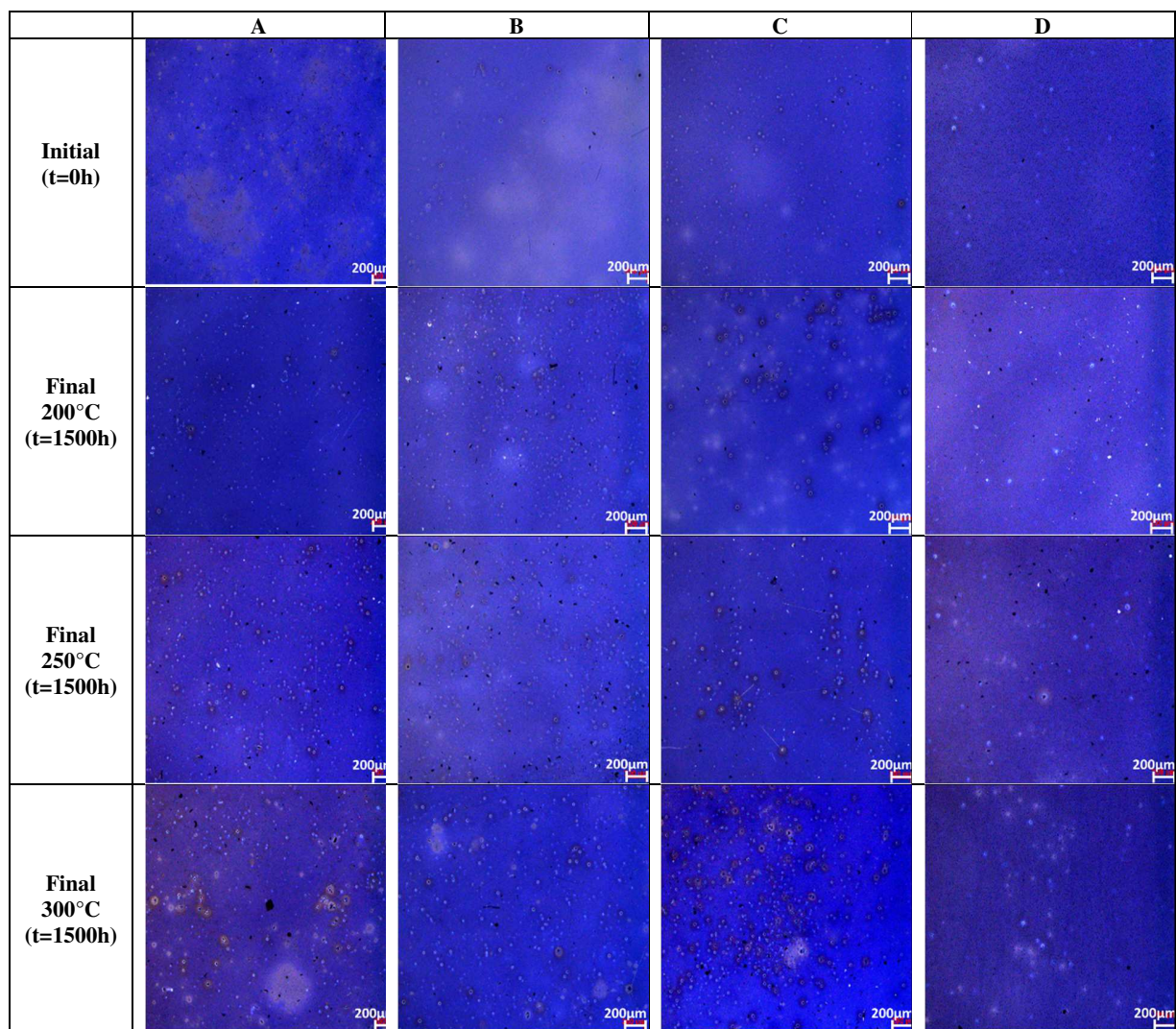


FIGURE 6. Optical microscope images of the four samples before and after the Constant temperature test (1500h)
Zoom: X10 / Scale: 200 µm

3.6. UV-5X test

Table 7 shows a summary of the transmittance and the contact angle differences after the UV-5X test for the four coatings. Concerning the transmittance results, a loss between 0.5 to 2.0% was detected after 1600h. This loss is the most important for the coatings A and D, and almost negligible for the coating B. On the contrary, the hydrophobic character of the thin films have been improved on every samples with an increase of the contact angle between 9.5 to 32.3°. Regarding the visual inspection in Figure 7, some bubbles are visible on every samples. This effect may be due to the temperature inside the chamber (~70°C). The coating A shows an important change of color, that proves a degradation of the thin film after 1600h. In conclusion, the two most resistant coatings to this accelerated aging test are the coatings B and C.

Coating	$\Delta\tau_{(sw)}$ (%)	$\Delta\theta_c$ (°)
A	- 1.3 \pm 0.4	+ 15.6 \pm 4.1
B	- 0.5 \pm 0.4	+ 18.7 \pm 11.3
C	- 1.0 \pm 0.2	+ 32.3 \pm 4.5
D	- 2.0 \pm 0.3	+ 9.5 \pm 2.7

TABLE 7. Summary of the results after the UV-5X test (1600h)

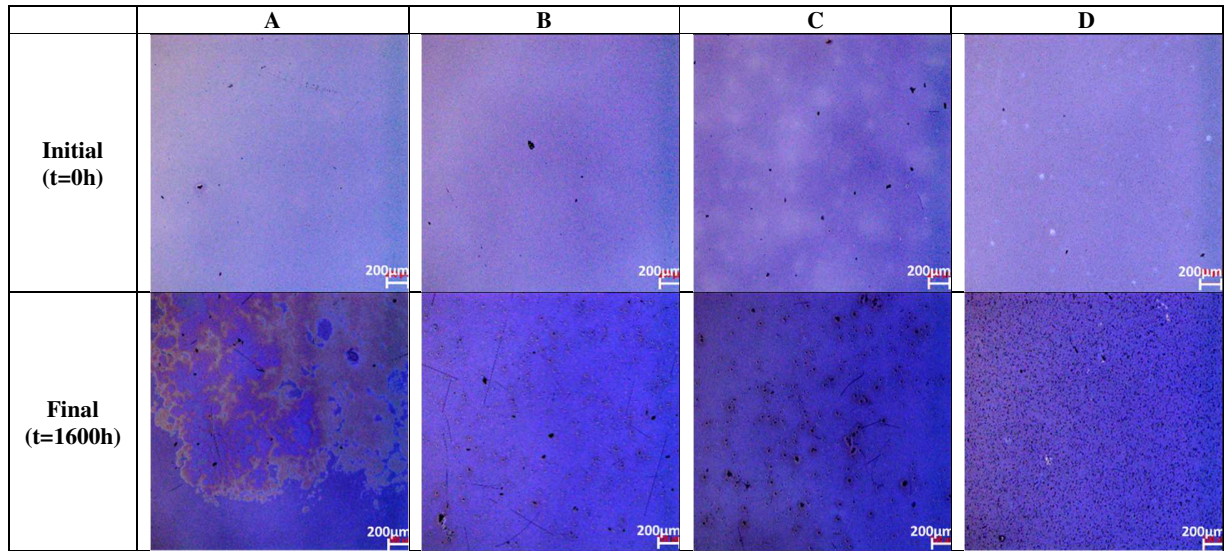


FIGURE 7. Optical microscope images of the four samples before and after the UV-5X test (1600h)
Zoom: X10 / Scale: 200 µm

4. Discussion

As discussed in the introduction, one of the goal for the industrials is to reduce the cleaning needs to improve water saving and minimize the cost of maintenance. One solution is to deposit an anti-soiling coating on the glass surface and maintain its high optical performances during 25 to 30 years. For that, some glass samples coated with an anti-soiling film have been aged in several climatic chambers, for testing the durability of their transmittance and hydrophobicity under aggressive conditions.

All the results reported in this paper are summarized into the Figure 8. After 3000h in the climatic chamber, the NSS test shows a considerable loss of transmittance and contact angle for some coatings, probably due to the degradation of the thin film caused by the salt solution. The Damp Heat test is one of the most aggressive test because of the simultaneous high temperature and humidity. Indeed, after an aging test of 1500h, a severe loss of transmittance can be noted for the majority of the samples. On the contrary, the hydrophobic character of the four thin films have been largely improved. This effect could be due to the temperature inside the chamber (~65°C) which probably makes the sol-gel layer denser and improves the stability and the hydrophobicity of the coatings. The Xenon radiation with water spray test is also an aggressive test because it reveals a considerable loss of transmittance and contact angle after 2000h, certainly because of the thermal shock due to the alternation between water and irradiation. We also observed watermarks on all the samples due to the evaporation front of the droplets during the drying phase. This evaporation front creates characteristic dewetting patterns on the sample surface probably due to the corrosion of the hydrophobic coating [25][26][27]. For the thermal test, the three high temperatures tested inside the climatic chamber during 1500h improve the stability of the thin films and increase largely the transmittance values for every coatings. The results are quite better when the temperature is not too high. However, these high temperatures also create a lot of bubbles on the surface and cause a decrease of the

hydrophobic character of the coatings, especially for a temperature higher than 250°C. The UV-5X test is also one of the less aggressive test in term of transmittance after 1600h of exposure. However, the hydrophobic character of the thin films have been largely improved for every coatings.

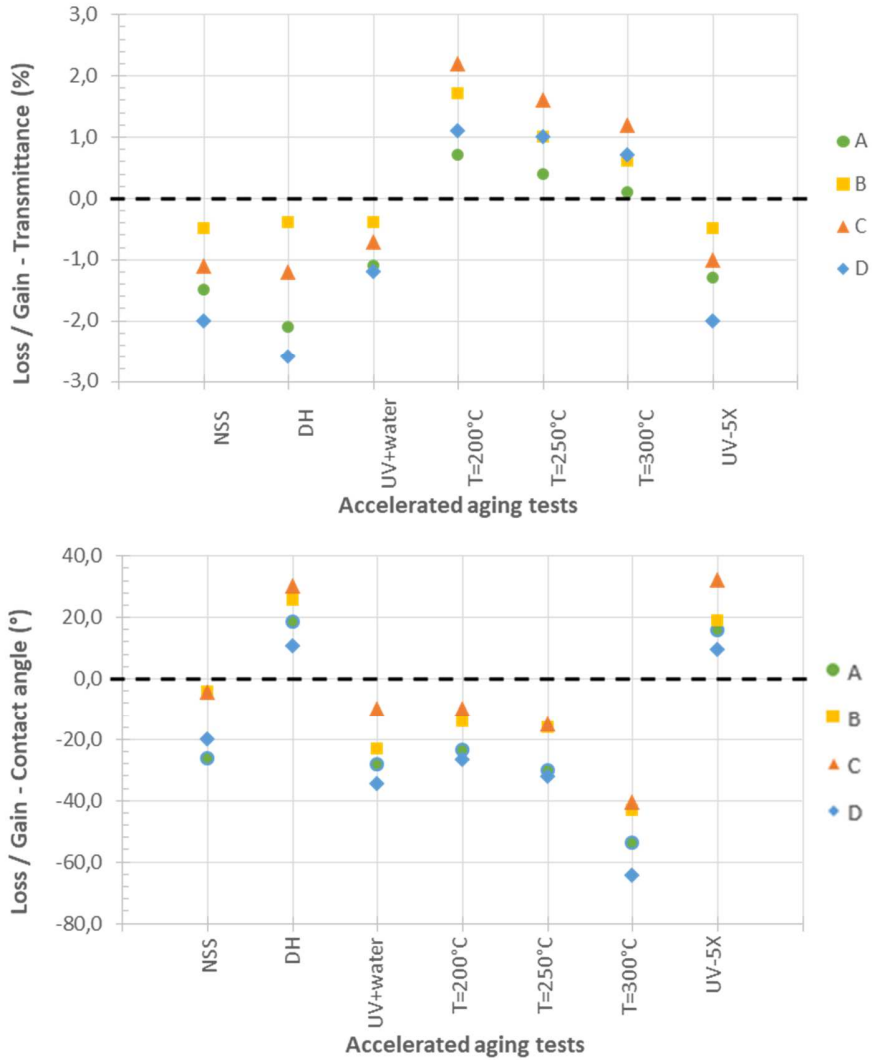


FIGURE 8. Summary of the transmittance and contact angle results for the five accelerated aging tests

5. Conclusions

In this study, absorber glasses were exposed under artificial climatic conditions for testing the effect of the temperature, the humidity, the irradiation and the saline mist on the four different anti-soiling coatings. Indeed, stress factors have a very strong environmental impact on the durability and therefore on the optical performances of the CSP components. The five accelerated aging tests performed on these coatings showed interesting results. According to the previous results, the coatings B and C (sol-gel solution composed by SiO₂ nanoparticles) seem to be the strongest ones in terms of transmittance, hydrophobicity and surface aspect. They recorded the smallest losses of optical performances despite the aggressiveness of the accelerated aging tests. For all the tests, they are much better than the commercial coating A and the other new coating D (sol-gel solution composed by SiO₂ nanoparticles).

The results presented in this paper are the first part of the study. Subsequent to that, the coatings B and C have been deposited on larger absorber glasses which have been exposed on several CSP sites. In a few months, the feedback will allow to know if the results of accelerated aging tests are consistent with the natural aging on-site, and therefore to validate the most durable anti-soiling coating.

Moreover, to measure their effectiveness, it would be interesting to study the impact of the soiling thanks to an artificial soiling test bench and/or a long exposure on real sites. In addition, it would be interesting to study the cleaning process. Indeed, the pressure of the water jet, the hardness of the brushes and the frequency of the cleaning operation could be very aggressive for the coatings.

Acknowledgments

The research leading to these results is realized in the frame of the WASCOP project [14] which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 654479, and also from French national funding from Agence Nationale de la Recherche on the program Investissements d'Avenir (n° ANR-11-EQPX-0014) for some equipments.

References

1. M. Kottek, J. Grieser, C. Beck, B. Rudolf, and F. Rubel, "World map of Köppen-Geiger climate classification updated" in *Meteorol. Z.*, vol. 15, pp. 259-263, 2006.
2. F. Trieb, C. Schillings, M. O'Sullivan, T. Pregger, C. Hoyer-Klick, "Global Potential of Concentrating Solar Power," in *SolarPACES Conference*, 2009.
3. R. Girard, C. Delord, A. Disdier, O. Raccurt, "Critical constraints responsible to solar glass mirror degradation", in *Energy Procedia*, vol. 69, pp. 1519-1528, 2015.
4. C. Avenel, O. Raccurt, J.L. Gardette, S. Therias, "Review of accelerated ageing test modelling and its application to solar mirrors", in *Solar Energy Materials and Solar Cells*, vol. 186, pp. 29-41, 2018.
5. M. Köhl, B. Carlsson, G. Jorgensen, and A. W. Czanderna, "Performance and durability assessment: Optical materials for Solar Thermal systems", in *Elsevier Science*, 2004.
6. International Renewable Energy Agency (IRENA), "Concentrated Solar Power – Technology Brief", 2015.
7. M. Mehos, C. Turchi, J. Vidal, M. Wagner, Z. Ma, C. Ho, W. Kolb, C. Andraka, and A. Kruiuzenga, "Concentrating Solar Power Gen3 Demonstration Roadmap", tech. rep., National Renewable Energy Laboratory and Sandia National Laboratories, 2017.
8. W.Q. Meeker, L.A. Escobar, V. Chan, "Using accelerated tests to predict service life in highly variable environments", in *Iowa State University Digital Repository*, 2000.
9. A. Fernandez-Garcia, L. Martinez-Arcos, F. Sutter, J. Wette, F. Sallaberry, R. Erice, T. Diamantino, M. Joao Carvalho, O. Raccurt, A-C. Pescheux, G. Imbuluzqueta, M. Machado, "Accelerated aging test of solar reflectors according to the new AENOR standard – Results of a Round Robin Test", in *SolarPACES Conference*, 2017.

10. O. Raccurt, A. Disdier, "Accelerated ageing tests for durability study of solar absorber coatings on metallic substrate for solar thermal energy (STE) application", in *SolarPACES Conference*, 2017.
11. IRENA, "The power to change: Solar and wind cost reduction potential to 2025", tech. rep., International Renewable Energy Agency (IRENA), 2016.
12. R.K. Jones, A. Baras, A. Al Saeeri, A. Al Qahtani, A.O. Al Amoudi, Y. Al Shaya, M. Alodan, S. Ali Al Hsaien, "Optimized cleaning cost and schedule based on observed soiling conditions for photovoltaic plants in central Saudi Arabia", in *IEEE Journal of Photovoltaic*, vol. 6, 2016.
13. O. Bouhafra, "Optimization of cleaning strategy project Noor I", technical report, Al Akhwayn University, 2017.
14. Water Saving for Concentrated Solar Power – WASCOP project (H2020): <http://wascop.eu/>
15. M. Faustini, B. Louis, P.A. Albouy, M. Kuemmel, D. Grosso, "Preparation of sol-gel films by dip-coating in extreme conditions", in *The Journal of Physical Chemistry C*, vol. 114, pp. 7637-7645, 2010.
16. F. Sutter, J. Wette, A. Fernandez-Garcia, T. Diamantino, M.J. Carvalho, F. Sallaberry, C. Sansom, O. Raccurt, "Guideline for accelerated ageing testing of reflectors for CSP", tech. rep., STAGE-STE project, 2018.
17. ISO 9227:2017, "Corrosion tests in artificial atmosphere – Salt spray test", in *International Organization for Standardization (ISO)*, 2017.
18. IEC 62108 10.7b, "Concentrator photovoltaic (CPV) modules and assemblies – Design qualification and type approval – Damp heat test", in *International Electrotechnical Commission (IEC)*, 2016.
19. ISO 16474-2, "Paints and varnishes – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps", in *International Organization for Standardization (ISO)*, 2013.
20. P.A. Van Nijnatten, "Directional and hemispherical solar-energy transmittance of single and double glazing", in *Optical Materials Technology for Energy Efficiency and Solar Energy*, vol. 1727, 1992.
21. ASTM Standard E903-96, "Standard test method for solar absorptance, reflectance and transmittance of materials using integrating spheres", in *ASTM International*, 1996.
22. ASTM G173-03, "Standard tables for reference solar spectral irradiances: direct normal and hemispherical on 37° tilted surface", in *ASTM International*, 2012.
23. D.Y. Kwok, T. Gietzelt, K. Grundke, H.J. Jacobasch, A.W. Neumann, "Contact angle measurements and contact angle interpretation – Contact angle measurements by axisymmetric drop shape analysis and a goniometer sessil drop technique", in *Langmuir*, vol. 13, pp.2880-2894, 1997.
24. L.S. Mok, K. Kim, "Equilibrium of a liquid in a spherical shell caused by gravity, surface tension, and van der Waals forces", in *The Physics of Fluids*, vol. 28, p.1227, 1985.
25. D. Zang, S. Tarafdar, Y. Tarasevich, M. Choudhury, T. Dutta, "Evaporation of a droplet: from physics to applications", in *Physics Reports*, vol. 804, pp.1-56, 2019.
26. R. D. Deegan, O. Bakaiin, T. F. Dupont, G. Huber, S. R. Nagel, T. A. Witten, "Capillary flow as the cause of ring stains from dried liquid drops", in *Nature*, vol. 389, pp. 827-829, 1997.
27. Li, D. Lan, Y. Wang, "Dewetting-mediated pattern formation inside the coffee ring", in *Physical Review E*, vol.95, 2017.