Abrasion and Cleaning Tests on Antireflective and Antireflective/Anti-soiling Coatings for Solar Glass Glazing

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Abstract

The application of antireflective (AR) coatings on glass components for solar thermal collectors and PV modules increases the solar efficiency by increasing the sun energy that reaches the active layer. The low refractive index of this material required to satisfy the condition of producing destructive interference in AR/glass interfaces, makes necessary to deposit porous silica layers which are mechanically weaker than dense silica layers. Soiling of AR coated glass glazing not only can reduce the solar transmittance and increase the scattering but also can deteriorate the surface of the AR coating leading to irreversible damage by abrasion and reducing the long-term performance. The use of an anti-soiling (AS) coating on the top of the AR surface could avoid this yield loss due to soiling and increases the durability of the solar device. This paper describes the effect on the soiling and cleaning of an AS treatment on AR coated glass samples. The effect of the sample soiling, the type of sand applied and the brush used has been studied. The AS coating not only affects the sample soiling but also diminishes the surface damage.

Keywords: Antireflective, anti-soiling, glass, cleaning, glazing

1. Introduction

It is widely known the use of AR coatings on glass covers to increase the efficiency of solar systems (PV and solar thermal technologies). The most common commercial AR coatings for glass consist of a porous silica layer which satisfies the low refractive index requirement. The porous structure is linked to weak mechanical properties which are essential to assure long-term performance. In addition, its surface is more reactive than uncoated glass surfaces, being more susceptible to soiling. The interaction between dust particles and AR coatings on glass has been already studied by Klim et al. (2015). This soiling affects performance and durability of the system and decreases its optical efficiency. Concerning the effect of climatic conditions, it has been found that high precipitation accompanied by high wind velocity create a natural cleaning, but the combination of dust with low precipitation or high humidity produces mud patches that cause an opposite effect and may result in permanent decrease in solar efficiency (Mazumder et al., 2015). Recently, the application of AS treatments on the AR coated glass is generating great interest as the transmittance by soiling is reduced as well as the abrasion produced by sand particles and/or cleaning processes is also diminished (San Vicente et al, 2011; Pendse et al., 2018; Quan and Zhang, 2018; Wiesinger et al., 2018). Additionally, cleaning processes of optical surfaces in solar power plants is a key point as they can degrade the optical surface and as these processes imply important operation and maintenance (O&M) costs in manpower. Water availability is also required in locations where it is costly and difficult to obtain it. In fact, European Union Horizon 2020 projects as WASCOP or MinWaterCSP are focused on reducing the water consumption in CSP plants by strategies as using new concepts of cleaning and the application of AS coatings. This work presents the results of applying contact cleaning on artificially soiled glass samples coated with an AR coating and the effect of using a commercial AS treatment on them. The sample resistance to abrasion of cleaning, the effect of the type of brush and the type of sand used for the artificial soiling are studied by transmittance measurements and visual inspection.

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2. Experimental

2.1 Sample preparation

Borosilicate flat glass samples with a thickness of 3 mm and a size of 1000 mm x1000 mm were coated with a silica sol-gel solution by dip-coating. The solution was composed of Tetraethyl orthosilicate (TEOS), Methyltriethoxysilane (MTES), water and ethanol being the molar ratio alkoxide:water:ethanol of 1:5:48 respectively. Hydrochloric acid was used as catalyst and Triton X-100 was added at 30 g/l concentration as a pore generator (Morales, 2002). Samples were heated at 500ºC for 15 minutes to burn the pore generator and other organic matter and to obtain the AR porous silica film. In some of the samples, a commercial solution (ClearShield Eco-System™) was applied on one side for preparing the hydrophobic AS surface. This AS solution was applied with a cotton pad wetted with the solution.

2.2. Soiled Sample preparation

Two types of sand taken from highly representative sites of CSP plants were employed. One of them was collected from The Sustainable City at Dubai (UAE) and the other from the Ouarzazate Solar complex in Ouarzazate, Morocco. Both sands present very different properties between them regarding colour, particle size and composition. A detailed characterization of both sands used has been performed by Fernández-García et al. (2018). Before soiling the samples, the sands were sieved with a sieve size of 180 µm. Some samples were artificially soiled with the described sands, using the next procedure: demineralized water was sprayed on the AR or AS/AR coated glass to wet the surface; then, 1g of sand was deposited with the fingers over the entire surface and demineralized water was sprayed again.At least 12 hours were waited before testing.

2.3 Cleaning test and Characterization

The equipment used in the cleaning/abrasion test is an Erichsen Washability and Scrubbing Tester model 494, equipped with a microdose pump and a metal holder. The test procedure was performed according to UNE-EN ISO 11998:2006, and consists in moving linearly and horizontally a wetted brush that is mounted on a metal holder on the sample surface. 200 cycles were applied meanwhile demineralized water was added with a feed rate of 4 mL per minute, being one cycle the brush movement over all the length in two-ways. Two brush types with different properties were used and nominally labelled as “soft” and “hard”. The soft brush is manufactured with nylon bristles of 0.1 mm thickness meanwhile the hard brush is made of pig bristles according to DIN53778. The equipment and both brushes used are shown in Figure 1.

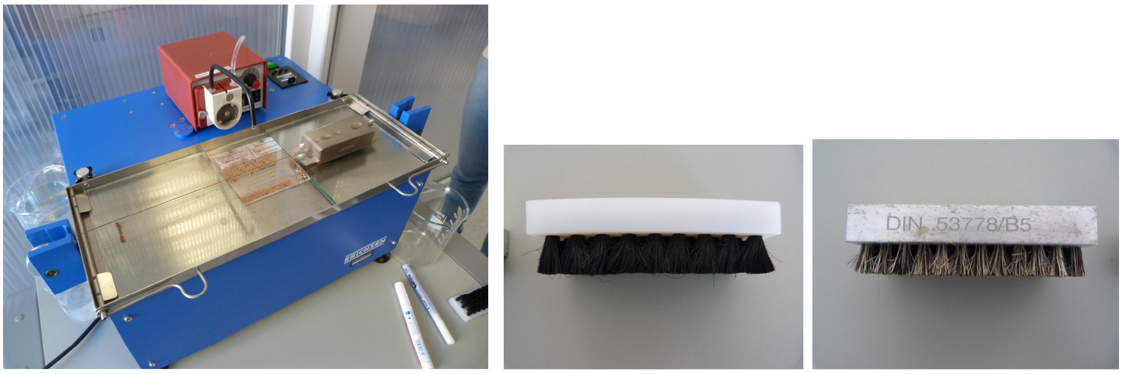


Fig. 1: Photographs of the equipment used during the test (left) and the two types of brushes tested (“soft” on the centre and “hard” on the right).

The effect of soiling and resistance at the cleaning test was evaluated by measuring the hemispherical transmittance spectra of the samples at the wavelength range of 300-2500nm. The equipment used was a UV/VIS/NIR Perkin-Elmer LAMBDA 950 double beam spectrophotometer with a 150-mm diameter Spectralon® coated integrating sphere. The solar transmittance ($\tau_{s,h}$) was calculated by averaging the transmittance data over the direct AM1.5 solar spectral irradiance given by the current standard ASTM G-173-03, following the IEC62862-1-1 standard as it is expressed in equation 1.

$$\tau_{s,h}(300,2500)=\frac{\int_{300}^{2500}\tau_{\lambda,h}(\lambda)G_b(\lambda)d\lambda}{\int_{300}^{2500}G_b(\lambda)d\lambda} \qquad \text{(eq. 1)}$$

Where $\tau_{\lambda,h}(\lambda)$ is the spectral hemispherical transmittance and $G_b(\lambda)$ is the spectral direct solar irradiance.

An optical microscope Leica DM4 M was used to study the microscopic appearance after the cleaning test. Additionally, water static contact angle (WCA) measurements were performed with a KSV CAM 200 instrument to study the effect of the commercial hydrophobic treatment.

3. Results and Discussion

3.1. Effect of AS treatment on soiling behaviour and solar transmittance

The effect of applying the commercial AS treatment on the surface of the AR coated glass is clearly shown when water is sprayed on the sand applied on the sample surface, as it can be seen in Figure 2. When the water was sprayed on the sand deposited on the AR coated glass, the sand remained uniformly distributed on the surface. However, when the same procedure was made on the AS/AR surfaces the sand was dragged with the water drops, leaving many places of the surface clean. The WCA measurements show the modification of the AR surface after applying the hydrophobic treatment, being the value increased from around 55º to 100º. Photographs of the water droplets on the surface before and after the AS treatment are also shown in Figure 2.

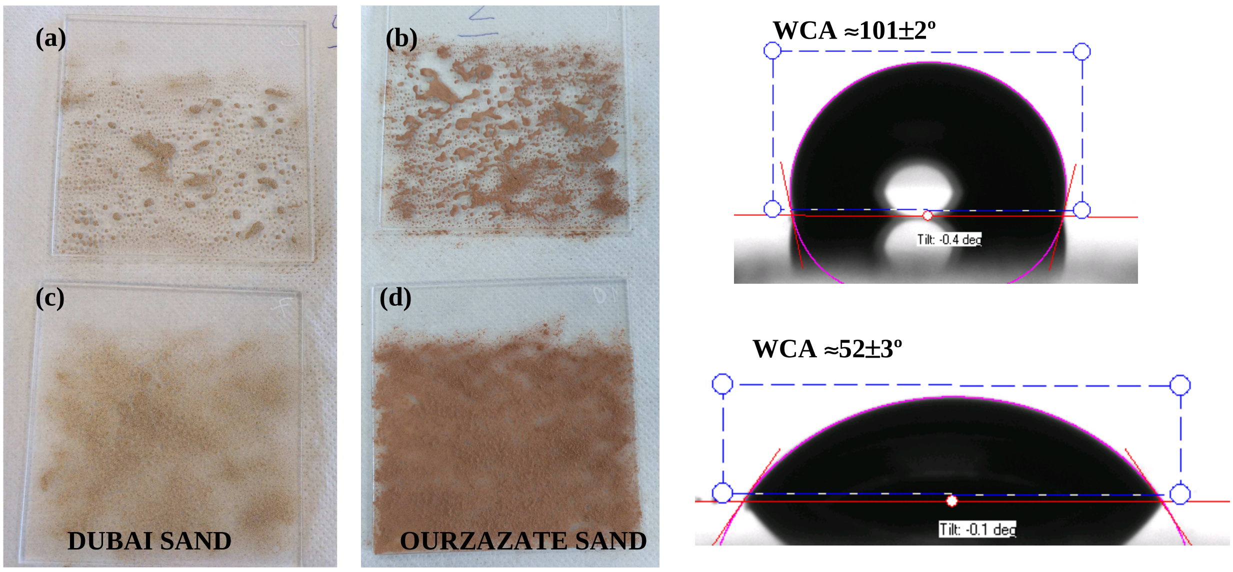


Fig. 2: Picture of AS/AR samples ((a) and (b)) and AS samples ((c) and (d)) after Dubai and Ouarzazate sands application (left and center, respectively). Photographs of the water droplets obtained in the static water contact angle (WCA) measurements in the AS/AR sample surface (top right) and in the AR sample surface (top bottom).

The AS treatment changes slightly the optical properties of the samples, as it can be seen in Tab. 1. The application of the AR coating increases remarkably the solar transmittance of the glass, being this value for the uncoated glass around 0.920 and around 0.975 after depositing the porous silica coating. When the AS treatment is applied, the solar transmittance decreases less than 0.010 points, obtaining values between 0.965 and0.972. The solar transmittance of the samples soiled with both types of sand are also presented in Tab. 1 and it can be seen that an important decrease is obtained. Noticeable differences are observed when the samples with the AS treatment are soiled, being the solar transmittance more than the double of the same samples without the AS. It should be noted that the three transmittance spectra are recorded in different zones of the same sample to minimize mistakes, and that the standard deviation is higher in the samples with AS than without AS, due to the heterogeneities in soiling (pictures in Fig.2). The values shown in Tab. 1 are the mean values of the three measurements. Moreover, an influence of the sand used is also observed, presenting the samples soiled with

Ouarzazate sand lower solar transmittance values than the samples soiled with Dubai sand. This is attributed to the smaller-size particles of Ouarzazate sand that have more specific surface area and are distributed more uniformly than coarser dust particles, reducing the voids between the particles through which light can pass. The same effect of particle size in soiling has been already observed previously by Klim et al. (2016) and Javed et al. (2016).

As conclusion, it can be remarked that the AS treatment modifies the artificial soiling with natural sand from Ouarzazate and Dubai, being the solar transmittance loss in average of 40% when the AS treatment is applied and of 78% without AS treatment. Moreover, the same quantity of Ouarzazate sand produces higher transmittance loss than Dubai sand.

Tab. 1: Solar transmittance values of AR coated glass before and after applying the AS treatment and after being artificially soiled.

	Solar transmittance ($\tau_{s,h}$)			
Sample	**Initial**	**After AS**	**Soiled (Ouarzazate sand)**	**Soiled (Dubai sand)**
AR	0.976	-	-	0.244
AS/AR	0.976	0.967	-	0.681
AR	0.975	-	0.207	-
AS/AR	0.976	0.972	0.524	-

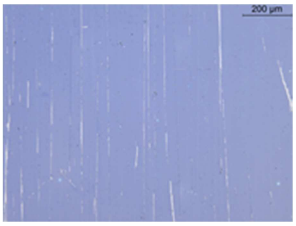
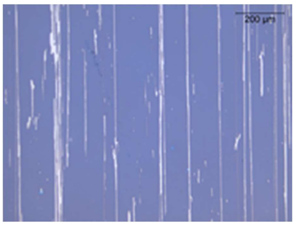
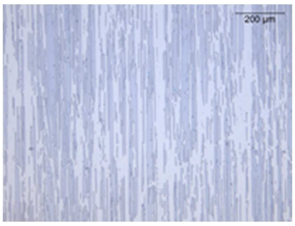
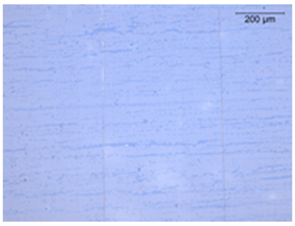
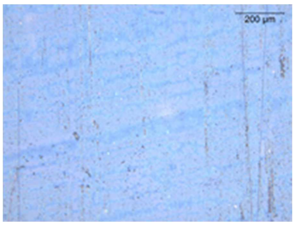
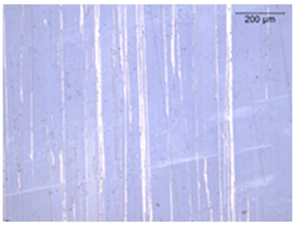
3.2. Contact cleaning Test

The effect of the AS treatment, the sand and the brush used during the contact cleaning test is examined in this section.

Effect of sand and AS treatment

The images obtained by optical microscopy from AR and AS/AR coated glass after the cleaning experiment with the soft brush are presented in Tab. 2, for samples without soiling and artificially soiled with Dubai and Ouarzazate sands. Furthermore, the solar transmittance variation of all the samples tested with respect to the value before testing is presented in Tab. 5. By analysing the images and solar transmittance values, it can be seen that the presence of sand or not strongly affects to the surface abrasion and optical performance. When no sand is present on the surface, very few scratches are made by the brush and even no scratches are visible when the AS treatment is applied. In fact, a -0.003 decrease in solar transmittance was obtained for the AR sample and no decrease for the AS/AR sample. When samples were previously soiled, the damage is more significant and in both cases (AR and AS/AR samples), and greater damage is produced when the sand used was from Ouarzazate. The solar transmittance drop values showed in Tab. 5 perfectly confirm the results obtained by the images. It is important to note that the application of the AS treatment diminished the damage produced by the cleaning in all the cases and in fact no damage is produced without sand. The same trends were obtained for the sample tested by using the hard brush (see next section).

Tab. 2: Optical microscopy images of AR and AS/AR samples after the cleaning test with soft brush, and without sand, soiled with Dubai sand and soiled with Ouarzazate sand.

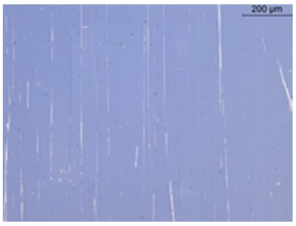
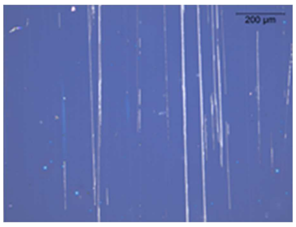
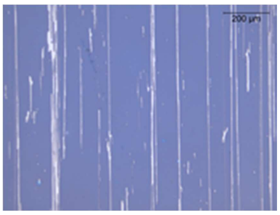
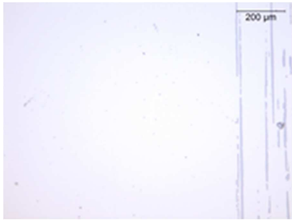
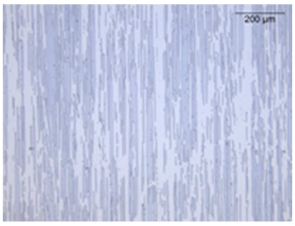
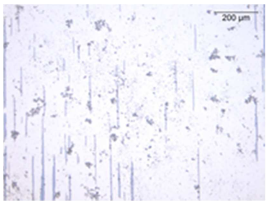
No sand (not soiled)	Dubai Sand	Ouarzazate sand
AR samples		
		
AS/AR samples		
		

<u>Effect of brush type and AS treatment</u>

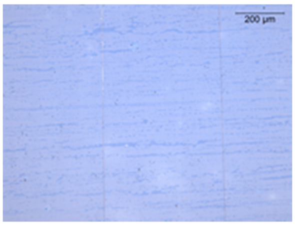
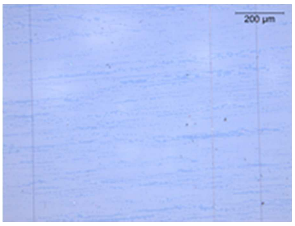
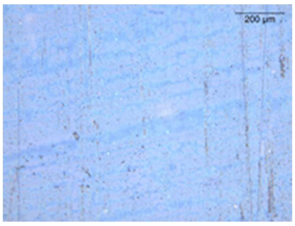
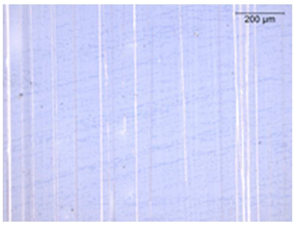
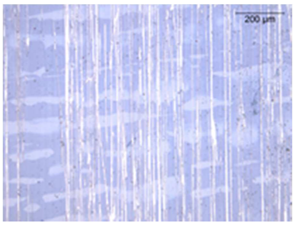
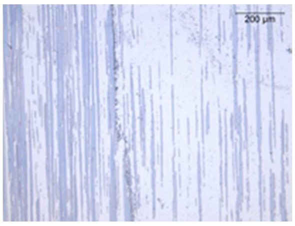
Tab. 3 and Tab. 4 show the images of samples tested comparing the two types of brush, not soiled and soiled for AR and AS/AR coated glasses, respectively. With regards to the AR samples, the images clearly show that the soft brush causes less surface scratches than the hard brush. Thus, soiled samples images show that the AR coating was practically removed in the tested side after the cleaning test with the hard brush. In the case of Ouarzazate sand, it can be also noticed some sand remainder that is not completely removed. The solar transmittance drop values (Tab. 5) show the same tendency, being the highest drop obtained (-0.029) the corresponding to the AR sample tested with the hard brush and the Ouarzazate sand.

Regarding the AS/AR samples, the role played by the brush type is similar to that played in the AR samples. The harder the brush, the more scratched the sample surface. It should be noted that when the samples were not soiled, not damage is produced independently of the brush type used. So, the application of the AS treatment allow to use the hard brush when the samples are not artificially soiled. It is also remarkable in these soiled samples that scratches are produced but less than in the case of the AR samples. The solar transmittance drop is nearly one-half of what they are in the samples without the AS treatment, as it is recorded in Tab. 5. This strongly suggests that the AS treatment not only avoid the adherence of sand particles but also increases the abrasion resistance of the surface. Similar results were obtained previously in samples tested in a sandstorm chamber, where the use of the AS treatment reduced considerably the erosion rate (Wiesinger et al., 2018).

Tab. 3: Comparison of optical microscopy images of AR samples after the cleaning test with the two different brushes.

Soft brush	Hard brush
AR – no sand	
	
AR- Dubai sand	
	
AR- Ouarzazate sand	
	

Tab. 4: Comparison of optical microscopy images of AS/AR samples after the cleaning test with the two different brushes.

Soft brush	Hard brush
AS/AR – no sand	
	
AS/AR - Dubai sand	
	
AS/AR Ouarzazate sand	
	

Tab. 5: Results of solar transmittance drop from all the samples after the contact cleaning test.

	Soft Brush		Hard brush	
	AR	**AS/AR**	**AR**	**AS/AR**
No sand	-0.003	0.000	-0.003	0.000
Dubai sand	-0.005	-0.004	-0.023	-0.004
Ouarzazate sand	-0.023	-0.013	-0.029	-0.016

4. Conclusions

This work shows the effect in transmittance and soiling behaviour of applying a commercial AS treatment on the AR coated borosilicate glass for solar components. The importance of studying the properties of the sand of each location has been demonstrated and so small-size particles adhered strongly to the surface produce higher surface damage, with the corresponding loss in transmittance. The contact cleaning method can be used on the samples but the erosion produced will be dependent of the soil level and type of samples, as this damage is produced by the joint action of the brush with the sand. Finally, the application of the AS treatment decreases slightly the solar transmittance but makes more difficult the adhesion of sand in presence of humidity and moreover improves the abrasion resistance to cleaning processes.

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