Guidelines

ACCELERATED AGING TESTING OF ALUMINUM REFLECTORS FOR CONCENTRATED SOLAR POWER

Version 1.1

August 2016

Authors: F. Sutter (DLR), J. Wette (DLR), A. Fernández-García (CIEMAT), S. Ziegler (Alanod), R. Dasbach (Almeco)

With contributions from Radia Lahlou (MASDAR)

Contents

Page

Foreword

The creation of this guideline has been funded by the German Federal Ministry for Economic Affairs and Energy under the grant agreement number 0325420 (Alumir project) and the European Commission within the FP7 Programme under the grant agreement number 609837 (STAGE-STE project).

Many researchers and institutions of the aforementioned projects are also involved in the SolarPACES Task III "Solar Technology and Advances Applications", whose objective is, among others, to design procedures and techniques for the development of improved materials for solar thermal energy. This guideline is open to amendments and updating as the state of the art advances. Please, send comments or suggestions to florian.sutter@dlr.de.

1 Scope

This testing guideline specifies the recommended accelerated aging conditions to reproduce realistic degradation mechanisms on aluminum reflectors, which have been observed during a 3 year outdoor exposure testing campaign at 9 exposure sites with 9 different aluminum reflector types (7 of them protected with a SiO_2 based sol-gel coating, 2 of them protected by a polymeric coating). Accelerated aging parameters have been derived to simulate the exposure after 3 and 10 years at three reference outdoor scenarios: “extreme desert”, “desert” and “coastal”.

The parameters have been achieved by averaging the 9 tested material types. However, if the material to be tested deviates significantly in its chemical composition, it is likely that other degradation mechanisms will be accelerated and the correlation to the outdoor reference scenarios will not apply. Fig. 1 shows the materials to be tested under the scope of this guideline. In any case, the indicated correlation to the outdoor reference scenarios can only be considered as an estimate. For some of the 9 tested materials the correlation applied better than for others. The expected uncertainty is 4.4 % (pp) specular reflectance, ρ, at a wavelength, λ, of 660 nm, an incidence angle, θ_i, of 15° and an acceptance angle, φ, of 12.5 mrad to simulate 3 years of exposure on the desert and coastal sites. For the “extreme desert” site the expected uncertainty is considerably higher because of the strong dependence on specific abrasion effects on site. The simulation of 10 years of exposure is based on extrapolation of the available outdoor data after 3 years.

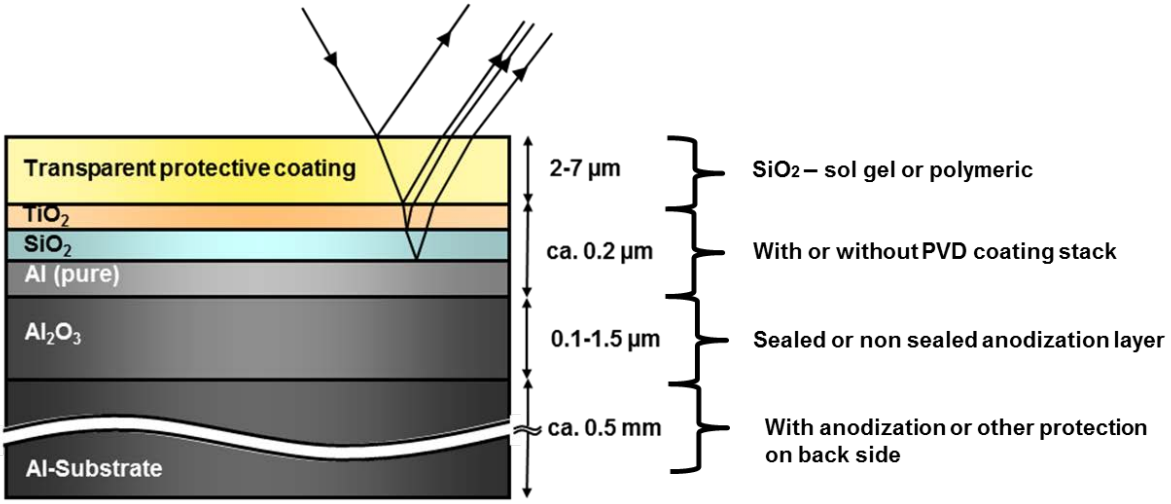

Figure 1: Materials to be tested within the scope of this guideline

2 Normative references

The following referenced documents are necessary for the application of this guideline. The references are undated; the latest edition of the referenced document (including any amendments) applies:

[1] ISO 9227: Corrosion tests in artificial atmospheres - Salt spray tests

[2] DIN 52348: Testing of glass and plastics; abrasion test; sand trickling method

[3] ISO 16474-3: Paints and varnishes - Methods of exposure to laboratory light sources - Part 3: Fluorescent UV lamps

[4] SolarPACES guideline: Parameters and method to evaluate the solar reflectance properties of reflector materials for concentrating solar power technology. (Available online: http://www.solarpaces.org/tasks/task-iii-solar-technology-and-advanced-applications/reflectance-measurement-guideline)

3 Terms and definitions

The herein named “extreme desert”, “desert” and “coastal” exposure reference sites refer to the conditions shown in Table 1. The sites are not located closely to industrial factories, mines or similar facilities releasing industrial pollutants. They represent exposure conditions of relevant North African CSP sites.

The Time of Wetness (TOW) refers to annual percentage of time, in which the temperature is above 0 °C and the relative humidity is above 80 % (as according to ISO 9223).

The minimum and maximum values of the presented irradiance data in Table 1 are absolute values per area (W/m²). Instead of the average value, the annual irradiance per area (kWh/m²/a) is given.

Table 1: Conditions of the reference sites

Meteorological parameter		Tempera-ture [°C]	Wind speed [m/s]	Relative humidity (RH) [%]	Time of Wetness (TOW) [%]	Direct Normal Irradiance (DNI)	Global Horizontal Irradiance (GHI)	Comments
Extreme Desert	Avg.	23.9	3.8	23.4	0.9	2133 kWh/m²/a	2174 kWh/m²/a	Frequent occurrence of sand storms
	Min.	-1	0	2	-	-	-	
	Max.	45	19	98	-	1090 W/m²	1241 W/m²	
Desert	Avg.	19.5	3.3	45.9	9.5	2141 kWh/m²/a	1965 kWh/m²/a	-
	Min.	-4	0	3	-	-	-	
	Max.	44	21	100	-	1084 W/m²	1173 W/m²	
Coastal	Avg.	19.7	5.3	71.3	71.5	1360 kWh/m²/a	1925 kWh/m²/a	Distance to coast < 5 km
	Min.	9	0	12	-	-	-	
	Max.	33	15	100	-	984 W/m²	1107 W/m²	

4 Sample preparation

The tested samples should be representative for the manufacturing line. Small samples (e.g. 100x100 mm²) can be cut out of the final product from running production and used for testing. If the edges are protected in operation outdoors, then the same edge sealing shall be applied on the samples.

The samples shall be handled with care. The surface may only be touched with gloves. Before optical characterization, the sample shall be cleaned with demineralized water and a soft tissue. After drying, remaining dust particles shall be removed with compressed air (filtered to remove particles larger than 5µm and any traces of compressor lubricants). During measurements contact between the sample surface and sharp and hard parts of the testing equipment (e.g. reflectometer support screws) shall be minimized, for example by covering the respective parts with a suitable mask.

5 Sample characterization

The following parameters shall be reported after the accelerated aging sequence:

Reflectance loss:

- Solar weighted hemispherical loss $\Delta\rho_s([300,2500],\theta_i,h)$
- Monochromatic hemispherical loss $\Delta\rho_\lambda(\lambda,\theta_i,h)$
- Monochromatic specular loss $\Delta\rho_\lambda(\lambda,\theta_i,\theta_r,\varphi)$ (at the same wavelength as for $\Delta\rho_\lambda(\lambda,\theta_i,h)$)

Degradation results:

- Maximum edge corrosion penetration (mm)
- Number of localized corrosion spots in the reflective aluminum layer >200µm per tested area
- Number of visible localized blisters in the protective coating per tested area

A full characterization shall be performed before the first and after the last accelerated aging test of the testing sequence described in chapter 6. Specular and hemispherical reflectance shall be measured according to the actual version of the SolarPACES reflectance guideline [4]. The standard deviations of the measurements and uncertainties of the used reflectometer and spectrophotometer shall be reported. The samples shall be measured in the exact same positions before and after the accelerated aging tests. As a minimum, 5 monochromatic specular measurements and 3 spectral hemispherical measurements shall be taken on a 100x100 mm² sample. The 5 monochromatic measurements obtained with a reflectometer shall be taken in the center of the sample and close to the 4 corners of the sample. The measurement shall not be taken closer than 10 mm to the sample edge or areas that have not been exposed to the testing conditions (e.g. due to the sample holder). The spectral hemispherical measurements obtained with a spectrophotometer shall be taken in the center of the sample. The sample shall be rotated after each measurement by 90° (to obtain measurements at 0°, 90° and 180°).

Figure 2 shows an example of the measurements taken on a 120x120 mm² sample. The herein used reflectometer and spectrophotometer have a measurement spot of 10 mm diameter and 9 x 17 mm², respectively.

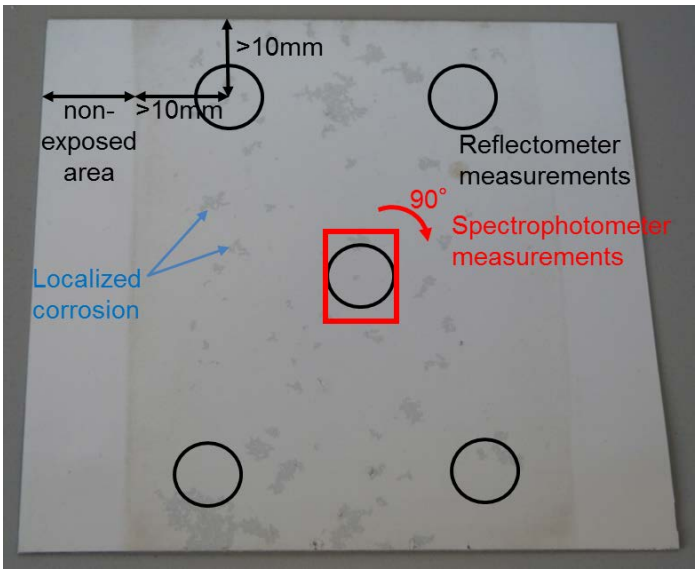

Figure 2: Exemplary measurements taken on a 120x120 mm² sample with localized corrosion spots

The appearing edge corrosion penetration or number of localized corrosion spots after the durability tests can be evaluated by optical microscopy or image processing tools.

Intermediate analysis (e.g. after each step in the testing sequence) provides additional information on the failure mechanism and is recommended.

6 Accelerated aging sequence

Table 2 shows the testing parameters to simulate 3 or 10 years of exposure at the “extreme desert”, “desert” or “coastal” reference scenario.

The sample shall be tested as-received from the manufacturing line in the first test, and then subsequently undergo the following tests of the sequence indicated in Table 2.

The sample shall be cleaned with demineralized water and a soft tissue after each test. Remaining sand particles from the erosion test and corrosion products shall be removed. The samples shall be cleaned immediately after the corrosion test, to prevent further corrosion trough condensed salt solution on the surface.

Additionally, after the final test the surface shall be carefully cleaned with a 9 % vol. HCl solution and rinsed with an ethanol-water solution (50 %/50 % v/v) followed by demineralized water immediately afterwards.

All tests are performed according to the standards cited in section 2, except two amendments for the sand trickling test DIN 52348: the used test sand shall be synthetic silica with a particle size between 300 and 625µm (instead of 500 to 710µm) and the impact angle shall be 30° (instead of 45°).

Table 2: Accelerated aging testing sequence

	Accelerated aging step		1	2	3	4
Method	**Simulated reference site**	**Simulated Years**	**ISO9227: CASS Test [testing time in h]**	**DIN 52348: Sand trickling [sand mass in g]**	**ISO9227: CASS Test [testing time in h]**	**ISO 16474-3, Method A, cycle No. 1 [testing time in h]**
A1	Extreme Desert	3	-	180	2	480
A2		10	-	600	8	480
B1	Desert	3	-	5	8	480
B2		10	-	15	24	480
C1	Coastal	3	96	5	8	480
C2		10	312	15	24	480

7 Reporting

The test report shall contain:

- A reference to this Guideline
- An information on the testing sequence applied (Method A1…C2)
- All measured parameters from section 5 (before and after accelerated aging)
- Used equipment with corresponding uncertainties
- The required parameters to be reported from the corresponding standards of the individual tests