Assessment of Solar Selective Absorber Coating Stability and Durability: Pertinence of Purely Thermal Aging vs. Real Concentrated Solar Aging

Audrey Soum-Glaude[1], **Alex Carling Plaza**[2], **Théo Grifo**[2], **Martin Bordas**[2], **Laurent Dubost**[3] **and Laurent Thomas**[2]

[1] PhD, CNRS Research Engineer, PROMES-CNRS laboratory (PROcesses, Materials, Solar Energy, www.promes.cnrs.fr), 7 rue du Four solaire 66120 Font-Romeu Odeillo, France, +33 468 307 747, Audrey.Soum-Glaude@promes.cnrs.fr

[2] PROMES-CNRS laboratory, Perpignan/Odeillo, France

[3] HEF-IREIS (Institut de Recherche en Ingénierie des Surfaces, www.ireis.fr), Saint-Etienne, France

1. Introduction and motivations of the work

To increase their solar-to-heat conversion (heliothermal) efficiency, the metallic surface of Concentrated Solar Thermal (CST) receivers is often covered with multilayered Solar Absorber Coatings (SACs) having high absorptance in the solar range, or Solar Selective Absorber Coatings (SSACs) also having low thermal emittance in the infrared range to limit radiative thermal losses. Under CST operation, receiver and coating materials are exposed to harsh working conditions for long durations: high concentrated solar irradiation, significant temperature levels and variations, air, water vapor, pollutants, aerosols, etc. These conditions represent potentially damaging sources of degradation, that may cause the premature aging and degradation of the receiver and coating materials, and degrade the overall efficiency of the plant. Therefore, to remain efficient and reduce maintenance costs, the receiver should ideally be covered by a highly stable coating, able to maintain its thermo-optical performance (solar absorptance, thermal emittance, heliothermal efficiency) for long durations under these detrimental conditions.

Most coating developers only rely on purely thermal aging protocols to study the thermal stability and estimate the durability of their SSACs, as they are relatively easy to implement. Indeed, these protocols consist in exposing samples of the coated receiver material to different temperature levels (around and above the aimed working temperature) and atmospheres (vacuum, ambient air, etc.) for various durations (from a few hours to several weeks) using a standard electrical furnace, and following the evolution of their thermo-optical performance with these tests. The assumption for the reliability of these tests is that phenomena leading to the degradation in thermo-optical performance are only thermally-induced ones, following Arrhenius laws with temperature, such as atomic diffusion (between layers of the coating and with the metallic receiver itself) and oxidation (incorporation of oxygen from ambient air).

Considering the complex nature of real CST working conditions, as mentioned above, the pertinence and limits of such purely thermal protocols to provide a valuable analysis of SSACs stability and durability are discussed in this paper (see also [1]). Indeed, applying thermal aging alone may not be sufficient for a complete assessment of the absorber aging behavior, especially considering no concentrated solar radiation is applied in these tests, contrarily to the aimed CST applications.

Our analysis is based on a critical literature review and an extensive experimental study conducted at PROMES-CNRS [1] on high temperature TiAlN-based SSACs samples provided by HEF-IREIS [2, 3]. The study compares the aging conditions and effects on these samples of purely thermal aging using an electrical furnace vs. real concentrated solar thermal aging using the Solar Accelerated Aging Facility (SAAF) at PROMES-CNRS [4]. In addition to the exposure to concentrated solar radiation ($C \approx$ 50-500), SAAF also allows applying thermal shocks and rapid thermal cycling, simulating representative CST conditions.

The aim of this work is to discuss the specificities, comparability and pertinence of these two aging procedures vs. the intended CST application, and provide recommendations for coating developers on whether simpler purely thermal aging protocols can really provide representative aging behavior assessment, or if including solar aging in SSACs aging strategies is also necessary.

2. Results highlights and conclusions

Table 1 compares calculated irradiance levels received and absorbed by our SSAC during purely thermal aging in an electrical furnace vs. solar exposure (SAAF), from reflectance/emittance spectra of typical solar irradiance in Odeillo and concentrators in SAAF, the alumina tube in the electrical furnace and the SSAC. The level of irradiance absorbed by the SSAC is much higher in CST than under purely thermal aging, whatever the spectral range, and especially in the solar region.

Irradiance levels (kW/m² = kJ/m²/s) / *spectral range*	**Purely thermal aging** (electrical furnace)		**Solar aging** (SAAF 50 kW/m²)		**Solar/thermal ratio**
	Received	***Absorbed***	***Received***	***Absorbed***	***Absorbed***
UV (0.28 – 0.4 µm)	_	_	0.55	0.52	∞
Solar (0.28 – 2.5 µm)	0.002	0.001	50	45.3	33000
IR (1 – 25 µm)	10.3	1.8	17.3	13.4	7

Table 1: Estimated irradiance levels in different spectral ranges for the two types of aging applied

Our experimental study indicates that there seems to exist different space and time scales (irradiance also being the instant energy density in kJ/m²/s) between: (i) slow and global thermally-induced physicochemical phenomena in purely thermal aging, caused by thermal accumulation on the material, until their activation energy is reached; (ii) spontaneous and localized irradiation-induced phenomena in CST aging (photon-matter interactions) caused by energetic UV-Vis photons, inducing chemical bond breaking and formation. Combined to high temperature, these photonic phenomena seem to promote and accelerate the thermally-induced aging phenomena observed when applying purely thermal aging, without changing their nature and effects at a more macroscopic scale, and consequently the thermo-optical performance.

Applying purely thermal aging tests could therefore be sufficient for coating developers in a first approach, provided they are applied at sufficient (representative or accelerated) temperature levels, pertinent working atmosphere and representative durations (several hundreds of hours), as demonstrated by our results. Despite its more complex implementation, solar aging remains nonetheless a recommendable step in the study of SSACs durability, as it provides more representative aging conditions, close to the aimed CST applications, that provoke additional and possibly synergistic effects in combination with high temperature.

Acknowledgments

The authors thank for their financial support: the French "Investments for the future" programme managed by the National Agency for Research (ANR) under contracts ANR-10-LABX-22-01-SOLSTICE and ANR-10-EQPX-49-SOCRATE; the ANR through projects ASTORIX (award n°ANR-14-CE05-0015) and NANOPLAST (award n°ANR-19-CE08-0019, nanoplast-project.cnrs.fr); the Occitanie Region and the European Regional Development Fund (FEDER) through Vadum-CSP project; the EU H2020 Research and Innovation Programme through SFERA III Project (GA No 823802); the Indo-French Center for the Promotion of Advanced Research (CEFIPRA) through project n°5908-1. The authors thank C. Escape, Y. Gorand, E. Hernandez, R. Garcia, T. Pouit and S. Fabert for their technical help.

References

[1] A. Carling Plaza, Accelerated aging and durability of selective materials for concentrating solar power plant receivers, PhD thesis, Université de Perpignan, 2021 (tel.archives-ouvertes.fr/tel-03611325).

[2] M. Bichotte, L. Dubost, T. Pouit, A. Soum-Glaude, A. Le Gal, H. Glenat, D. Itskhokine, AIP Conference Proceedings, 1734 (2016) 030006.

[3] A. Carling-Plaza, M.A. Keilany, M. Bichotte, A. Soum-Glaude, L. Thomas, L. Dubost, AIP Conference Proceedings, 2126 (2019) 020001.

[4] R. Reoyo-Prats, A. Carling Plaza, O. Faugeroux, B. Claudet, A. Soum-Glaude, C. Hildebrandt, Y. Binyamin, A. Agüero, T. Meißner, Solar Energy Materials and Solar Cells, 193 (2019) 92-100.