Solar Energy Materials and Solar Cells 186 (2018) 29–41

Contents lists available at ScienceDirect

Solar Energy Materials and Solar Cells

journal homepage: www.elsevier.com/locate/solmat

Review of accelerated ageing test modelling and its application to solar mirrors

Coralie Avenel[a,b], Olivier Raccurt[a,*], Jean-Luc Gardette[b,*], Sandrine Therias[b]

[a] Univ. Grenoble Alpes, CEA LITEN, Thermal, Biomass and Hydrogen Department, Thermodynamic and Solar Systems Laboratory, F-38054 Grenoble, France; INES, F-73375 Le Bourget du Lac, France

[b] Université Clermont Auvergne – CNRS - SIGMA Clermont, ICCF F-63000 Clermont–Ferrand, France

ARTICLE INFO

Keywords:
Solar mirrors
Concentrated Solar Power (CSP)
Ageing test
Acceleration factor
Modelling
Lifetime prediction

ABSTRACT

Solar mirrors for concentrated solar power (CSP) plants are expected to last at least 30 years. As this delay is far too long to obtain useful information regarding in-service degradation, accelerated approaches to weathering testing are performed by manufacturers and research laboratories in order to quickly assess the lifetime of commercial or new technologies. However, most published studies that have been performed in the CSP field are based on phenomenological approaches. The characterization of the degradation, which mostly considers reflectance loss, has rarely been linked to physical or chemical processes that are responsible for the degradation of properties. Furthermore, the general laws that can be established from these data to establish material behaviour are empirical.

Ageing tests have been used for many years in other fields, particularly in the domain of polymeric materials. The impacts on the material properties of stress factors such as temperature, irradiation and humidity have been extensively studied, and models have been proposed for different kinds of materials, even though most are based on empirical observations. One of the goals of this article is to determine how these models could be applied to the weathering of solar mirrors, and as such, the goal of this paper is to provide a critical review of the various models that are most used and accepted by the scientific community. All of these models include material-dependent parameters, and the values that have been determined in these studies are reported here to list their order of magnitude.

1. Introduction

1.1. Solar mirrors for CSP

Concentrated solar power (CSP) plants are a carbon dioxide-free and renewable way to produce energy in which sunlight is concentrated by mirrors on an absorber that heats a fluid. The different kinds of CSP technologies and their historical developments have already been reviewed [1–9] and therefore are not presented here. Power plants only use direct normal irradiation (DNI) and consequently must be installed in specific locations that meet several requirements such as high DNI, large plane land, etc. Trieb et al. [10] determined potential locations for CSP plants on Earth, which are shown in Fig. 1.

Obviously, the stress factors within these locations are rather aggressive (light, temperature, humidity, etc.), and as a consequence, the exposed materials are susceptible to rapid degradation of their properties [11–13]. It is known that plants are profitable only if the lifetime of their components, and in particular that of mirrors, exceeds 30 years [14,15]. Issues involving durability then become a bottleneck in bringing products to the market.

Durability can be defined in many ways, but the most generally accepted definition is that durability is the period of time during which a product in its service environment will survive before requiring replacement or maintenance. The weathering resistance of mirrors exposed to all of these stresses should then be evaluated to predict whether or not a technology is adapted to an implantation site. Mirrors can be classified as 3 types including glass, aluminium and polymer mirrors [16,17]. Glass mirrors can be monolithic or laminated. All of these structures are shown in Fig. 2. Several plants using glass monolithic mirrors have been installed and exploited since the 1980s [9,18–21], and little degradation has been observed on the mirrors. However, mirror technologies have evolved since, and new mirrors in the market are different from those installed in these plants [22]. Indeed, the backing system of paints used to contain large amounts of lead to improve stability; nevertheless, recent environmental regulations require a drastic decrease in lead content, or even complete removal [23]. As a

* Corresponding authors.
E-mail addresses: olivier.raccurt@cea.fr (O. Raccurt), luc.gardette@uca.fr (J.-L. Gardette).

https://doi.org/10.1016/j.solmat.2018.06.024
Received 9 April 2018; Received in revised form 7 June 2018; Accepted 12 June 2018

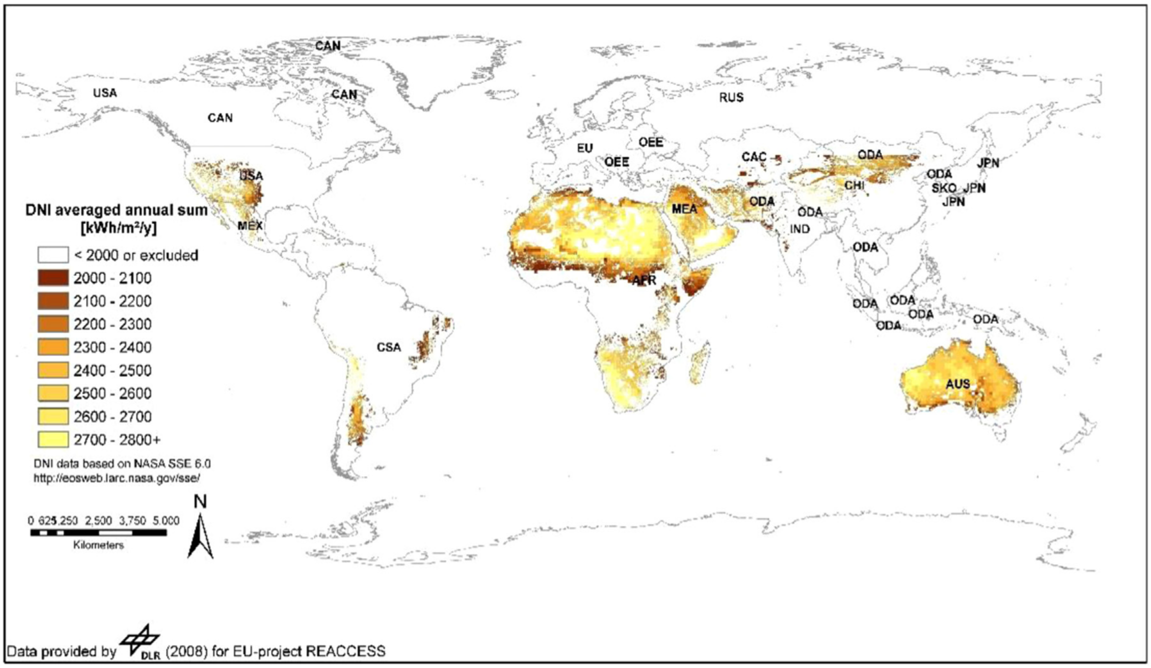

Fig. 1. Map of potential locations for CSP plants [10].

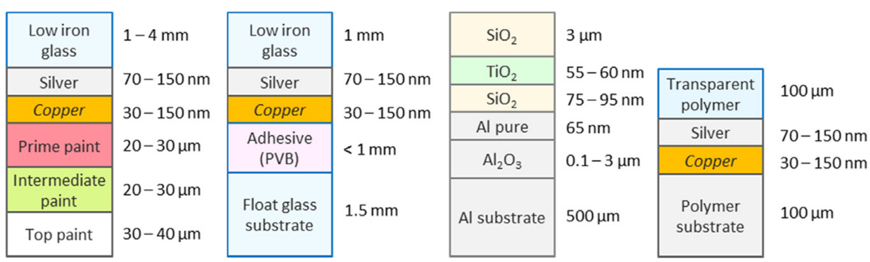

Fig. 2. Structures of (left to right) monolithic glass [11], laminated glass, aluminium [33] and polymer mirrors [34] with a magnitude order of layer thicknesses.

consequence but also in order to reduce costs, manufacturers have developed new coatings [24], new designs [25] and new technologies (or have updated the old ones), aiming to make the devices lighter and easier to shape. These adaptations include aluminium [26–29], polymer [30–32] and glass laminated mirrors, and their efficiency and durability over the course of 30 years has not yet been proven.

The back side of monolithic mirrors is protected by a paint system. The binder of such paints is a polymer or a mix of polymers, holding together other elements such as inorganic fillers and pigments, which provide desired protective properties such as anti-UV, oxygen and water barriers [33]. Laminated mirrors contain a polyvinyl butyral (PVB) layer to affix the two glass parts together. Polymer mirrors, as their name suggests, have a polymer top layer and often a polymer substrate. Only aluminium mirrors do not contain polymers. In this regard, it seems relevant to base the study of mirror lifetime on the methodologies and models developed in the polymer field.

On the other hand, all solar technologies are confronted with more or less similar environmental conditions, and so it is also relevant to base this review on solar fields such as photovoltaic and solar thermal technologies.

1.2. Methodology for service life prediction

Reliable methodologies are required to provide quantitative lifetime durability projections that support correct design decisions at the earliest phases of product development. Relevant data should be obtained in shortened times, and one could expect that this would allow for establishing models to predict the lifetime and the performance evolution of the product under normal use [34].

The goal of any accelerated weathering test is to increase the rate of degradation of material properties. Methodologies must be developed in order to assess the fate and the lifetime of new mirror technologies. As stated above, this kind of methodology already exists in other domains, with general methods developed by statisticians [34–36] or methods applied in research fields such as those of polymers, paints and coatings [37–39] or microelectronic fields [40,41], even for other solar technologies [42,43]. All of these domains have a technological maturity that is greater than that of CSP, and many of durability studies have already been performed [44–46]. This could help in establishing novel procedures that could be applied to the specific case of mirrors. In particular, the experience gained in the domain of polymers is a substantial asset, which has proven that an appropriate combination of testing conditions and set of methods assessing weather-induced changes allows for a better understanding of property changes.

A general methodology for evaluating durability and lifetime can be explained in the 4 steps described below [34,43]:

Define a performance requirement and a way to monitor the functional properties that are associated with the performance.

Identify environmental conditions to define the main stress factors that are responsible for the loss of properties and measure their level in a representative location. This allows establishing a hierarchy of the stress factors that considers a probability of occurrence at the application site. Meteorological data from sites all over the world are monitored, in particular in the framework of weather prediction and can be