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Retrofitting of solar glasses by protective anti-soiling and -graffiti coatings

M. Barletta [a,*], M. Puopolo [b], V. Tagliaferri [a], S. Vesco [a]

[a] Dipartimento di Ingegneria dell'Impresa, Università degli Studi di Roma "Tor Vergata", Via del Politecnico 1, 00133 Roma, Italy
[b] Dipartimento di Ingegneria Meccanica ed Aerospaziale, "Sapienza" Università degli Studi di Roma, Via Eudossiana 18, 00184 Roma, Italy

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ABSTRACT

The present investigation proposes the design and manufacture of organic–inorganic hybrid silicone-epoxy anti-soiling coatings for the retrofit of "already-in-use" glass panels. Synthesis of the anti-soiling formulation, setting-up of the deposition and drying process and analysis of the operational parameters were investigated. The resulting coatings were characterized in terms of micro-mechanical and tribological response and resistance to chemicals. In addition, the anti-soiling and anti-graffiti performance against inorganic dusts, carbonaceous pollutants and permanent markers was tested according to standardized procedure. The silicone-epoxy coatings were found to protect the glass substrates from soiling with contaminants, showing a high potential to preserve the initial efficiency of the related solar-energy systems over long time.

1. Introduction

The long time performance of solar-energy systems in residential, commercial, agricultural and industrial applications is strictly dependent on a large number of parameters among which sun irradiance content and spectral contents can be even marginal factors [1]. In contrast, environmental issues like climate, exposure and geographical location of the plant as well as inherent systems and components performance can play a major role [2]. In this respect, soiling and, in particular, the impact of the sedimentation of dust and dirt particles on the cleanliness status of the surface of solar panels can be of a fundamental importance. If underestimated, soiling can compromise the economic sustainability of a solar installation [3]. Soiling of the exposed surfaces acts as a solar screen [4]. It can limit or compromise the absorbance of the sun irradiance, reducing the power output or completely stopping the system [5]. The maintenance of the surface cannot be thus prevented, if the panel efficiency would be preserved at a reasonable level over time [6]. Maintenance is usually performed by accurate washing with water, detergents and manual or automatic brushing [7–9]. This entails an economic effort, considerable environmental impact related to the potentially pollutant chemicals involved and their dismissing and depletion of natural resources, often scarce in the country where most of the solar-energy systems are installed [10]. Maintenance costs should be carefully considered in the estimation of the overall competitiveness of each new installation and it normally erodes an important share of the expected profits [11,12]. The elimination of the maintenance cycles or lengthening of the time range between two consecutive cycles is of extreme interest to improve the potentiality of solar panels.

The application of overlay coatings on the surface of solar panels is not unusual [13]. It is expected to increase their absorbance when irradiated under the sun light [14]. However, other solutions include the application of surface overlay coatings with different features. For example, the employment of photo-catalytic coatings has been often pursued in the recent past [15]. Photo-catalysis is a process by which highly reactive hydroxyl radicals are generated when a semi-conductor, like TiO_2, is exposed to the light (i.e., also the sun light) with energy superior to its band gap and air humidity. These radicals act as powerful oxidants and are effective against organic matters by degradation reaction [16,17]. Coatings manufactured by direct synthesis of photo-catalytic TiO_2 on solar glasses using metal-organic precursors via the sol–gel route have been the matter of previous investigations [18]. However, temperature of 450 °C and over is required to promote a satisfactory yield of the reactive process. Similarly, vacuum or thermal spraying process could be used to generate active photo-catalytic films, but they both involve complex equipments and often high temperature [19,20]. For this reason, the development of TiO_2-based photo-catalytic coatings has also followed different routes, with nano-TiO_2 powders or, more properly, clusters dispersed inside "open pore" binders based on organic or organic–inorganic resin [21,22]. These

* Corresponding author. Tel.: +39 0672597195; fax: +39 062021351.
E-mail address: barletta@ing.uniroma2.it (M. Barletta).

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resins are designed to bind the nano-TiO_2 and avoid its rapid washout. At the same time, the open porosity of the resin is structured to avoid an excessive embedding of the TiO_2 in the binding phase and allow the partial contact between the active TiO_2 surface and contaminants to deal with. However, while photocatalysis is extremely effective on organic matters, it is nearly ineffective on inorganic compounds like dusts and dirty particles, a consistent share of environmental pollutants and most of bird guanos [21]. Such compounds can accumulate quickly on the surface of the solar panels and compromise their efficiency in short time [23]. An alternative is represented by the so-called anti-soiling coatings [24–26]. They are usually based on the very simple concept of super-oleophobic and super-hydrophobic screens [27]. These screens reduce the wettability of the surface versus both oleophilic and hydrophilic compounds and preserve the surface from soiling with water- or oil-driven contaminants. In the case of solar glasses, the hydrophobic screens would be of utmost interest as they could contrast the deposition of many contaminants as atmospheric dusts (i.e., often driven by the rain), environmental pollutions and bird guanos [28]. Therefore, synthesis and application processes of coatings based on metal-organic compounds and, in particular, on those structured with super-oleophobic and super-hydrophobic fluoro-organic groups abound in the scientific and technical literature [29–31]. Some of them were also industrialized [32]. These compounds are designed around tetravalent specie like Al, Zr or, more frequently, Si. They feature a triplet of hydrolyzable alkoxy −OR groups, where −R could commonly be a methoxy or an ethoxy group. They also feature an additional lateral chain, an organo-functional group, that confers most of the features to the metal-organic compound. In this case, the super-hydrophobicity is achieved through the graft of a fluoro-carbonic group (for example, a tridecafluoro-octyl $-F_{13}C_8$ group). These metal-organic compounds can easily react with silicate glasses through the −OH groups widely available on the glass surface [33]. The −OH groups on the glass surface can react with the hydrolyzed −OR groups of the metal-organic compounds by condensation, thus forming covalent Si−O−Si bonds and exposing the lateral fluoro-carbonic chains on the opposite side to generate the super-hydrophobicity. However, to ensure the establishment of a good covalent bonding among Si on the glass surface and Si in the core of the metal-organic compounds, a catalyzed synthesis developed at moderately high temperature (i.e., often well over 100 °C [31,34,35]) for long time (i.e., often over 10 min) is fundamental. Otherwise, the metal-organic compounds only bond weakly with the underlying glass, thus generating a film just poorly adhered on it. Despite the usage of metal-organic compounds is of extremely interest for any new installation, as the glass panels can be processed in a convective oven at the prescribed temperature to promote the linkage between the anti-soiling film from the metal-organic precursors and the substrate, it is inappropriate to retrofit the "already-in-use" solar panels. Retrofitting of "in service" solar panels can be only pursued with a material which can form a well adhered and solid coating without oven baking. The film should be generated through a simple deposition process, followed by a spontaneous drying.

The present investigation proposes the development of a highly transparent, weather proof and anti-soiling coating based on an organic−inorganic hybrid material. The coating structure is designed on a silicone skeleton that confers good hydrophobicity. The lateral chains consist of epoxy groups cross-linkable with amine-based organofunctional silane hardeners to confer both high mechanical, tribological and chemical resistance. Thus, this material is a silicone-epoxy resin. Despite the silicone-epoxy resins and, similarly, the organofunctional silanes feature some lateral −OH and/or −OR groups, through which they could bond with the glass substrates by reaction with the corresponding −OH groups, alternative routes to implement the deposition process should be pursued. In fact, the reaction between the −OH/−OR groups on the silicone-epoxy film and glass surface should be favored by the temperature, as well. As stated before, this route cannot be pursued when the coating process has to be performed on "in service" solar panels for retrofitting purposes. Indeed, silicone-epoxy resins are also characterized by a good potential to bond with a generic surface by "gluing". They can act as "self-drying" adhesives, whereas hardening is promoted by spontaneous drying through solvent evaporation. When still fluid, the silicone-epoxy resin acts as an adhesive which works its way into small pores of the substrate and ensures mechanical adhesion once dried. However, gluing silicone-epoxy resins onto flat glasses can be extremely troublesome, as this class of substrates can be characterized by a reduced or not-existent surface porosity. In this investigation, the glass surface was sand-blasted with fine glass beads to generate a minimal surface porosity, yet enough to ensure the anchoring of the silicone-epoxy surface overlaying layer, without altering the absorbance of the glass panel. Proper formulations of silicone-epoxy resins were designed and applied by automatic drawdown applicator on as-received and sand-blasted flat glass sheets. The process was followed by spontaneous drying to ensure the consolidation on as-received and sandblasted glass substrates. Characterization of the coating morphology, visual appearance, micro-mechanical and tribological performance, chemical endurance was carried out. Lastly, anti-soiling performance of the films against atmospheric dusts, selected pollutants and permanent markers were tested according to standardized procedures and guidelines of specific international regulations. The experimental findings showed the silicone-epoxy coatings suitable to protect the glass substrates from the rapid deposition on them of contaminants, showing a high potential to preserve the initial efficiency of the related solar-energy systems over long time.

2. Experimental

2.1. Materials

A high-solids 2-pack silicone-epoxy resin cross-linked with bis(trimethoxysilylpropyl) amine (amine H-equivalent, 335 g/mol) was used to coat flat substrates, 3.8 mm thick and 2.5×10 mm^2 wide, made from float glass. Thickeners (Tego Viscoplus 3030, Evonik, Essen, Germany) and flow promoters (Tego Flow 370, Evonik, Essen, Germany) were added to the formulation to achieve coatings smooth and with homogenous thickness through the strict control of the formulation rheology. Finally, an anti-sticky agent (Tego Rad 2250, Evonik, Essen, Germany), whose composition is proprietary, was added to confer super-hydrophobic effect to overlaying surface and promote the anti-soiling properties of the silicone-epoxy resin.

2.2. Manufacturing process

As-received glass substrates were cleaned in an ultrasonic bath using a solution of EtOH 95% for 30 s followed by rinsing in demineralized water. Some of them were sandblasted (6 bar, fine glass beads, sandblasting equipment, 0580, Fervi Srl, Modena, Italy) to modify the starting morphology and promote coating adhesion. After sandblasting, the substrates were rinsed in demineralized water to remove glass residuals from surface.

The silicone-epoxy formulation was deposited on both as-received and sandblasted glass by automatic drawdown bar applicator (Automatic Film Applicator L, BYK-Gardner, International) equipped with a doctor blade. The resulting coatings were left to cross-link at environmental temperature. After cross-linking,