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The influence of Sahara sand on the degradation behavior of float glass surfaces

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ABSTRACT

To guarantee a long life span and high quality performance of glass including devices, a deep understanding of glass corrosion processes is required. The influence of adhering particles on the degradation behavior of glass surfaces is little investigated yet. Studies of particle-glass surface interaction are of practical interest when it comes to several technical applications implying particle exposition besides natural weathering and storage. Sahara sand was chosen for the investigation of the influence of adhering particles on glass corrosion as one example of harsh environmental conditions. The scope of this work is on chemical changes and crystallization effects that are induced by the adhering sand.

Soda-lime-silicate glass produced in a float process and sand collected in the Moroccan Sahara have been investigated in this study. The glasses were weathered in a climate chamber (80 °C, 80% relative humidity) for up to 8 days - half of them with a thin sand layer, the other half without and subsequently compared to each other. The following investigation of the samples included optical and atomic force microscopy (AFM) as well as X-ray diffraction (XRD). Furthermore, X-ray photoelectron spectroscopy (XPS) combined with stepwise sputtering was used to generate element depth profiles and to investigate chemical changes of the glasses. The sand was examined with XRD and energy dispersive X-ray spectroscopy (EDX).

The study shows that the adhering sand drastically enhances the leaching of the network modifiers Na and Ca and furthermore adsorbs them. It also effects crystallization processes: For sand-free weathered glasses the formation of dendritic trona and massive sodium bicarbonate layers could be verified within this study. While sand-weathering the formation of carbonates is suppressed due to the adsorption of network modifiers by the sand and the formation of aluminosilicates on the glass surface is observed. These aluminosilicates would lead in ongoing weathering to more drastic corrosion damages than carbonates due to their high alkalinity. Hence, sand is not an inert material only lowering the light transmittance of glasses when covering them. It actively changes the properties of glass surfaces and fastens their degradation.

1. Introduction

Due to its cheap and easy production, its robustness and transparency, glass is a material with a wide application field, including coverages for solar cells. To optimize glass including devices and ensure a long life span as well as high quality performance, a deep understanding of glass corrosion itself is required. This degradation process is mainly determined by the chemical glass composition as well as several environmental factors like temperature, humidity and pollutant load of the air. Glass surfaces undergo aging processes like hydration due to humidity and interactions with atmospheric constituents like compounds of sulfur and carbon [1]. Hydration leads to alterations in the composition of the surface and hence in its mechanical properties. Common features of glass surface degradation are gel layer formation, network dissolution due to humidity and the formation of crystalline products caused by atmospheric components dissolving in the glass surface film [1–6]. These degradation mechanisms are not homogenously distributed over the glass surface and depend on the local pH-value as well [1,7]. The influence of adhering particles on the degradation behavior of glasses is little studied yet. Therefore, a simple particle-glass surface model was investigated in this study. The chosen particles are sand from the Sahara which provides a simple and but also very specified model to study the influence of adhering particles on glass corrosion. Besides particle exposition during weathering or storage, the obtained data are of practical relevance when it comes to photovoltaics: The latest approaches to secure the global power supply while facing a worldwide growing demand for electric energy deal with huge solar plants in several desert regions. For instance, solar panels in

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the Sahara could help to secure the power demands for many European and African countries. The solar cell coverages which are commonly made of float glass would face harsh environmental conditions, like drastic fluctuations in temperature, frequent dew in the mornings, intense UV radiation and sand load. Thereby, one has to distinguish between tribological-mechanical glass damages and glass corrosion caused by physico-chemical effects.

To our knowledge, weathering tests on float glasses combining all harsh environmental factors of a desert were not performed yet and only few works deal with the mechanical influence of sand load itself [8–15]. Their focus is the physical effect of abrasion by sandblasts on glass surfaces and its impact on the efficiency of solar cells. In this work, the scope is on the chemical changes as well as crystallization effects that might be induced by adhering sand. This study aims to ascertain if sand acts just as an inert material covering a glass surface and hence lowering its light transmission or if it actively effects and changes its surface properties, apart from abrasion. Therefore, weathering experiments on glasses under the influence of Sahara sand were performed. Afterwards, chemical depth profiles were generated using X-ray photoelectron spectroscopy combined with stepwise sputtering. Since the tin-doped bath and tin-free air side of a float glass feature different properties leading to different corrosion behavior, both sides were exposed to sand and investigated within this study [16].

2. Experiment

2.1. Glass samples and sand

For the experiment soda-lime-silicate glass produced in a float process was used. In this production process the glass melt is cooled down on a liquid tin bath which leads to a slight tin doping of the glass side that faces the bath (bath side) while the other side that faces away from it (air side or atmosphere side) remains tin-free. For this study, all experiments described in the following sections were performed for both sides of the glass samples. These had been stored for about two years in our laboratory. The major glass components are SiO_2 (72 wt%), Na_2O (14 wt%), CaO (9 wt%) and MgO (4 wt%). The aluminum oxide content is 0.56 wt% and the amount of iron oxide 0.09 wt%. The thickness of the glass samples is about 3 mm. They were cut into pieces of $\sim 2 \times 2\,cm^2$ and cleaned in an ultrasonic bath with methanol and isopropanol for 5 min, respectively.

The used sand originates from the Erg Zeher, a dune field in the southeastern Moroccan Sahara close to the Algerian border (29°41.347 N–5°59.347 W). This region is about 430 km away from the Mediterranean Sea and about 230 km from the Atlantic Ocean with the Atlas mountain range in between. The sand was collected from the very top of the biggest sand dune. It has a reddish appearance and its composition was analyzed by XRD and EDX.

Usually, weather induced corrosion effects occur after a long period of time. To accelerate the corrosion, a Binder climate chamber (KF 240) was used for weathering the samples. This enclosure enables the creation of specified, reproducible environmental conditions to which the samples are exposed to. For this study, its parameters were set at 80 °C and 80% relative humidity and the glasses inside stored under these conditions for 1, 3 and 8 days, respectively. To determine the influence of the sand on the corrosion behavior of the glass, two sample sets were made: One was weathered in the climate chamber with a thin layer of sand covering the glass surfaces ($\sim$0.1–0.15 g sand per sample), while at the same time the other one was weathered without sand in the same chamber and hence is used as the reference set. After taking the samples out of the climate chamber the sand was removed from the glass surfaces with a stream of compressed air.

The following nomenclature for the samples is used: The names of the reference glasses, weathered without sand, start with “Ref”, followed by the time of weathering in days and the abbreviation for air side (a) and bath side (b). Samples weathered with a sand layer start with “San”, the rest follows the same system. Hence, sample Ref8a is the investigated air side of a sample weathered without sand coverage for 8 days in the climate chamber.

2.2. Optical microscopy

To investigate changes in the surface topography on a large scale an optical microscope (Zeiss Axioscope) was used in different illumination modes, mostly phase contrast. To estimate the amount of crystals a small program was written in python using the OpenCV library and implementing its blob detection function.

2.3. Atomic force microscopy

Atomic force microscopy (AFM) measurements were performed with the Dimension Edge with ScanAsyst® by Bruker. The used tips consist of Si_3N_4 and have a radius ≤ 12 nm. The used mode was PeakForce Tapping®. The scan frequency was set between 0.6 and 1.0 kHz. With 265 lines per scans a surface region of $10 \times 10\,\mu m$ was investigated. The measurements were repeated for each sample on different spots of the surface.

2.4. XRD and EDX

The elemental and mineralogical phase composition of the sand was investigated using energy dispersive X-ray spectroscopy (EDX) and X-ray diffraction (XRD). The EDX measurements were carried out applying a SEM XL30 by Philips equipped with an EDX-Detector by EDAX. The applied acceleration voltage was 10 kV for the glass samples and 30 kV for the sand samples. The samples were measured during an integration time of 100 s.

For the XRD measurements a D5000 by Bruker was used in Theta-Theta geometry and a Cu-radiation source (wavelength: 0.154060 nm). The measuring range (2Θ) was from 10 to 80° using a step size of 0.02° and a time per step of 1.5 s. The measuring spot is $20 \times 1.5\,mm^2$. Rietveld refinement was used to calculate the ratio of crystalline phases.

2.5. XPS analysis

After performing the different experimental procedures the samples were introduced into an ultra-high vacuum system with a base pressure of $2 \cdot 10^{-8}$ mbar and investigated by X-ray photoelectron spectroscopy (XPS). A non-monochromatic AlKα-source (XR50 by SPECS Surface Nano Analysis GmbH) was used and operated at 300 W. The X-ray spot on the sample surface is about 1 mm in diameter.

After a first detailed characterization of the sample surface depth profiles were generated by repeated sputtering and measuring cycles. The sputter gun was operated with Argon and a beam energy of 3 kV sputtering an area of $10 \times 10\,mm^2$. The first 2 sputter cycles lasted 15 s to softly remove surface contaminations related to carbon adsorbates. The further sputter cycles lasted 45 s each, leading to a sputter rate of $\sim$0.33 nm/cycle as determined in [17]. The depth profiles were recorded until stable element signals were reached.

The measured spectra were analyzed with the CASAXPS software. Spectral fits were made using Gaussian-Lorentzian line shapes with a constant 30% Lorentzian component. The backgrounds were fitted by use of Shirley backgrounds. The same software was used for calculating the atomic concentrations on the basis of the measured peak intensities using the physical model described by [18]. The remaining sample charge was constant over time and in a range of about 2.7–3.2 eV. The spectra were calibrated to the C1s peak at 284.6 eV caused by aliphatic carbon adsorbates whose position is quite unaffected by the chemical environment and hence can be used as a calibration standard [18]. Therefore, in the shown spectra the binding energies are given in corrected form (cor. Binding energy). Furthermore, the measured data