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Modeling of soiling based on silica-soda-lime glass exposure at six European sites

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Abstract

Samples of silica-soda-lime float glass, a material selected as a pertinent soiling sensor, were exposed for up to 28 months at four urban sites (Athens, Krakow, London and Prague) and at a semi-urban one (Monte Libretti, near Rome), sheltered from rain. This exhaustive experience permitted to complete and to test the generalisation ability of the results previously obtained on the same material, exposed according to the same protocol, during 24 months, at a single site (Paris). The model previously fitted for the Paris experiment, the Hill equation, could be successfully generalised for four other sites of exposure (Athens, Krakow, Prague and Rome). The analytical form of this model was interpreted in terms of a physical description of the soiling phenomenon. Some of the model coefficients were different from one site to another, depending on the specific environment of exposure (air pollution levels, meteorological factors), while the other ones were rather equivalent. The analysis of the model coefficients, on the one hand, led to an estimation of the period after which soiling is close to its saturation level, and on the other hand, it will permit to correlate these coefficients to the environmental factors, in order to select the most appropriate ones for building dose–response functions for soiling, with broad geographical application.

Keywords: Soiling; Float glass; Particle deposition; Haze; Time evolution modeling; Hill equation

1. Introduction

One of the major aims of the EC MULTI-ASSESS Project[1] was to develop multi-pollutant deterioration models of wet and dry deposition of gases (SO_2, NO_2, O_3, HNO_3) and particulate matter on materials used in objects and monuments of the European Cultural Heritage. The deposition of airborne particles causes "a visual nuisance resulting from the darkening of exposed surfaces"; this phenomenon is called soiling (Beloin and Haynie, 1975; Haynie, 1986; Watt and Hamilton, 2003; Brimblecombe and Grossi, 2004, 2005) and the Project paid a special attention to this type of deterioration.

Silica-soda-lime glass was selected and used as a soiling sensor due to its properties discussed in Lombardo et al. (2005): briefly, it is weakly leached in

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[1] Model for MULTI-pollutant impact and ASSESSment of threshold levels for Cultural Heritage, http://www.corr-institute.se/MULTI-ASSESS.

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urban air pollution conditions, it has a smooth and non-porous surface and it is transparent. Moreover, modern glass is used world-wide and its composition varies between narrow limits.

Soiling is usually studied via optical parameters: reflectance, lightness, reduction of surface gloss (Beloin and Haynie, 1975; Creighton et al., 1990; Haynie, 1986, Lanting, 1986; Hamilton and Mansfield, 1993; Schwar, 1998; Adams et al., 2002). Other pertinent parameters for soiling characterisation were proposed by Lombardo et al. (2005) when studying soiling evolution in Paris: total mass of deposited particulate matter, total carbon, total water soluble ions, and haze (an optical property). This selection was induced by ASEM (analytical scanning electron microscopy) observations. During the 2-year exposure in Paris, all the four parameters followed a similar trend, proving that they reveal the same soiling phenomenon.

Several empirical models were proposed in the literature to study soiling evolution in time, such as: the square-root (Beloin and Haynie, 1975; Creighton et al., 1990; Pio et al., 1998; Grossi et al., 2003), different exponential forms (Schwar, 1998; Adams et al., 2002; Brimblecombe and Grossi, 2004; Lefèvre et al., 2005) or a sigmoid curve, the Hill equation (Lombardo et al., 2005). These models were obtained from experiments conducted on different materials (painted wood, concrete, brick, limestone, painted steel or window glass).

Few studies focused on the modern glass soiling, and even less on its modeling. Moreover, exposure conditions were not similar.

Schwar (1998) and Adams et al. (2002) measured the reduction of surface gloss of samples exposed horizontally, for up to 20 or 30 weeks, with a 1-week frequency. In both studies, soiling evolution in time was expressed by equivalent exponential forms.

Lombardo et al. (2005) exposed samples of modern glass vertically, as commonly used for windows and building façades, over a longer period (up to 24 months) and with a lower frequency of exposure (of several months). This exposure, conducted in Paris, will be called "the Paris experiment" in this paper. After testing the models previously proposed in the literature for soiling (square root, exponential), as well as different combinations of elementary functions, the least-squares best-fit model was found to be the Hill equation for the Paris experiment. Analytical forms such as linear or square-root were also tested and their fit was unsatisfactory; even if they had performed better, they couldn't be retained in this study of soiling because they increase to infinity with time, a hypothesis that was rejected from a physical point of view.

Although the fitting residuals were very low, the model fitted for the soiling time evolution in Paris is subject to some critical remarks: (i) it was built on a sparse data set (only 5 measurements were available by parameter, and the four soiling parameters were strongly inter-correlated); (ii) measurements correspond to particular sampling periods; (iii) data is obtained from a single-site experiment, remark also true for the previously cited works.

The MULTI-ASSESS project offered the opportunity of a multi-site experiment, permitting a comparison of the results obtained on the same material, using the same experimental protocol, but in different environments. Samples were exposed in five other European sites; the exposure duration was 4 months longer than in Paris and up to 8 measurements were available for each parameter. Moreover, samples were withdrawn with a different frequency than in Paris; it was thus possible to test if different sampling points lead to a different shape of the model.

This paper presents some results concerning modern glass soiling in Athens, Krakow, London, Prague and Rome. These new measurements permitted to generalise the model previously fitted in the Paris experience (the Hill equation). The purpose of this study is not to find the best fit model for each site individually, but to test if the best fit obtained in one experiment can be generalised for the others; the same model for different sites (even it is not the best for each one, individually) offers the opportunity to reveal the general trend and the particularities of the soiling evolution in different environments. The model obtained from the Paris experiment was chosen for generalisation because data seemed to be less noisy than for the other sites, and without outliers. Although it was selected as a black box model, the analytical form of the Hill equation could be interpreted in terms of a physical description of the soiling phenomenon. The model coefficients obtained for the different sites were then inter-compared and interpreted.

2. Materials and methods

Following the exposure protocol described by Tidblad et al. (2001), samples of silica-soda-lime float glass Planilux® (10 × 10 × 0.2 cm) were exposed vertically (the usual position of glass in buildings), for up to 28 months and sheltered from rain in a naturally ventilated box. In the MULTI-ASSESS project, five targeted exposure sites were selected: four urban sites (London, Prague, Krakow, Athens) and a semi-urban one (Monte Libretti, near Rome), to be called Rome in