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Maintenance costs for European zinc and Portland limestone surfaces due to air pollution since the 1980s

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ABSTRACT

The purpose of the reported research was to estimate maintenance costs, cost savings and lifetime increases for outdoor material surfaces in Europe, obtainable by reducing air pollution. Data and methodology from the ICP-materials project were used. The results suggest that for material surfaces exposed outdoor in Europe, a hypothetical 50% reduction in air pollution from present (2014) levels, would give an average overall increase in the near future lifetimes between maintenance due to atmospheric chemical weathering, of about 25%, and savings in maintenance cost of about 10%. It was found that for zinc monument surfaces since 1987 until 2014, the theoretical lifetime before maintenance has, on average for the ICP-locations, increased with about 125% (from 118 to 265 years). The additional average lifetime due to 50% pollution reduction would have been about 26%, representing maintenance cost savings sinking from about 20% in 1987 to 10% in 2014. For Portland limestone an increase in lifetime since 2002 until 2014, and additional lifetime due to 50% pollution reduction, of 35–40% was indicated, representing maintenance cost savings of about 14%. This would have been very significant cost savings considering the total use of zinc and Portland limestone as construction and façade materials.

1. Introduction

Atmospheric weathering of metals, stone and other construction materials causes huge maintenance costs. The atmospheric weathering is caused partly by air pollution (Watt, Tidblad, Kucera, & Hamilton, 2009). One expected effect of the reduced air pollution that has been observed in Europe over the last 30 years (Tidblad et al., 2014, 2017), is a reduction in maintenance costs for material surfaces, façades and built structures. This work presents estimations of probable maintenance costs for outdoor material surfaces in Europe due to the observed air pollution, and of cost savings that could have been obtained by reducing the air pollution. The estimations were made by applying data and methodology from the ICP-materials project[1] (ICP, 2018). The ICP-materials programme has since 1987 measured the atmospheric weathering of material samples and the values for the influencing environments at 55 exposure stations. Statistical dose-response functions developed in the ICP-materials programme were used in this work to estimate atmospheric chemical weathering costs.

Increased rates of atmospheric corrosion of built structures were observed over most of Europe in the second part of the 20th century (Kreislova & Knotkova, 2017). The high corrosion was caused mainly by burning of sulfur rich hydrocarbons and consequent increased concentration in air and deposition of sulfur dioxide (SO_2), and increased acidity in precipitation. In this situation the ICP-materials programme was set up. It exposed selected metals, stone and other material samples in a European wide exposure programme, which also included a few measurement sites in North America. The North American stations were in the range of the European environments, thus enlarging the database and relevance for what could be termed a "European situation". Measurements were performed for some longer periods of mainly four and eight years, and for 19 annual periods up to the present. The measurements are now ongoing in a trend programme with measurements every third year, and with new four and eight years exposures (ICP, 2018).

Fig. 1 shows a corrosion measurement site in the ICP-materials programme.

The aim of ICP-materials has been to explain the corrosion, to assess trends in, and tolerable levels of the corrosion, to calculate maintenance cost, and to map such parameters over the European geographical area (ICP, 2018; Watt et al., 2009). Towards the end of the century, control of SO_2 emissions and other changes in the industrial sector lead to reduction in SO_2 concentrations in air (EEA, 2017). A change to a

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[1] The International Co-operative Programme on Effects on Materials including Historic and Cultural Monuments, within the Convention on Long-range Transboundary Air Pollution (CLRTAP), organized under the United Nations Economic Commission for Europe (UNECE).

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Fig. 1. The ICP-materials station (no. 21, Appendix A) located in the urban background in Oslo, Norway (2012). The picture shows metal plate samples in unsheltered position (1), holder disks for passive pollution samplers to the left on the rack (2), shelters for samples in a box behind the metal samples (3a) and under a plastic shield to the right (3b), and a precipitation collector to the very right on the photo (4). Limestone samples mounted on a carousel can be seen through the upper left corner of the plastic shield (5a) and in the low insertion (5b).

multipollutant situation was generally observed, where the atmospheric corrosion of many materials were significantly influenced by several other air pollutants in addition to SO_2 (Kucera, 2005; Tidblad, 2014).

The reporting from ICP-materials since 1987, shows a significant decrease in atmospheric metal corrosion and maintenance cost over the recent 30 years, correlating with decrease in the concentrations of corrosive air pollutants, especially sulfur dioxide, SO_2 (Tidblad et al., 2014, 2017).

This new situation lead to the development, within the ICP-materials programme and in several EU projects (Kucera, 2005, 2007) of multi-pollutant dose-response functions for a range of metals and Portland limestone, based on statistical analysis of the measured corrosion and the impacting environmental parameters (Kucera et al., 2007; Tidblad, 2014). The programme today recommends the use of one of two sets of dose-response functions. One set for an "SO_2 dominated" situation and another set for a "multipollutant situation", depending on the air pollution situation.

The dose-response functions have been used to calculate maintenance costs for buildings and monuments due to atmospheric chemical weathering of their surfaces, depending on levels and changes in air pollution and climate loads (Doytchinov, Spezzano, Screpanti, & Leggeri, 2013; Grøntoft, 2017, 2011; Watt et al., 2009). This paper goes a step further by applying ICP-materials zinc and Portland limestone dose-response functions to calculate changes in such maintenance cost, over recent years and due to hypothetical pollution reduction, for selected ICP measurement sites and for the average of all the European, and three North American, ICP sites, representing a "European situation". Large total areas of zinc and limestone are exposed in facades and monuments in Europe (Fig. 2), and the total cost of their maintenance is clearly large. A significant part of this cost would be due to atmospheric weathering and corrosion impact on the surfaces (Grøntoft, 2017).

Atmospheric weathering of materials can, generally, be caused by chemical, physical and biological processes. Corrosion processes have been studied since the early 20th century. Atmospheric corrosion of metals is an electrochemical process with oxidation of the metal and inclusion of different anions, which are available in the environment, such as for example carbonate, sulfate and chloride (Graedel & Leygraf, 2000). The term "atmospheric corrosion" is also used for stone materials. It then involves chemical dissolution reactions, but could also include physical and biological processes (Watt et al., 2009).

In this work the terms "atmospheric chemical weathering" and "atmospheric corrosion" are used, interchangeably, but depending on context, such as type of materials and usage in referenced literature. The terms will, as used, not include major physical and biological degradation processes. Small-scale physical and biological processes that may occur together with experimental chemical weathering is however not excluded. The rate of the atmospheric chemical weathering depends on climatic factors, such as rain amounts and temperature, and on the chemical composition of the atmosphere, especially the amount of air pollution (Graedel & Leygraf, 2000; Watt et al., 2009).

2. Methods

This work applies dose-response functions reported from the ICP-materials programme, to estimate historical (since 1987) changes in maintenance costs due to atmospheric chemical weathering, and savings that could have been obtained due pollution reduction.

The calculations represent a selection of 23 urban, 8 industrial and 21 rural ICP-sites for zinc, and of 9 urban, three industrial and 8 rural ICP-sites for Portland limestone (Fig. 3 and Appendix A). Of the "zinc-sites", one (no 32, Appendix A) is termed urban-industrial, and one (no 57, Appendix A) "urban-rural" in the ICP-materials data base (Tidblad et al., 2014). Station no. 32 was therefore included in both the "urban" and "industrial" categories, and station no. 57 in both the "urban" and "rural", categories, when making separate calculations for the categories. The three North American stations were included in the study to fully represent the data available from ICP-materials.

The calculations were made with the zinc dose-response function for the SO_2 dominated situation (as information from recent exposures in ICP-materials indicate that the nitrate effect included in the multi-pollutant function (Tidblad, 2014) is uncertain (ICP, 2017)), and using the Portland limestone function for the multipollutant situation (Watt et al., 2009). Multi-pollutant dose response functions are also available from the ICP-materials programme for carbon steel, cast bronze and copper. Functions including chloride are also available (Sabbioni, Brimblecombe,& Cassar, 2010). Differently from the zinc function, the multi-pollutant functions for carbon steel and cast bronze include particulate exposure, measured as the concentration of particulates in air with average aerodynamic diameter smaller than 10 µm (PM10). PM10 has only been reported from the ICP stations in five years since 2002, for an average number of 9 stations per year. The copper function includes, besides SO_2, tropospheric ozone, O_3, which is a secondary