Available online at www.sciencedirect.com
ScienceDirect
Procedia Earth and Planetary Science 17 (2017) 320 – 323
Procedia
Earth and Planetary Science

15th Water-Rock Interaction International Symposium, WRI-15

Water-stone interaction in contemporary works of the built environment

Carlos Alves[a,1], Carlos Figueiredo[b], António Maurício[b]

[a]LandS/Lab2PT (UID/AUR/04509/2013; POCI-01-0145-FEDER-007528) and School of Sciences, University of Minho, Portugal
[b]CERENA - Centro de Recursos Naturais e Ambiente (UID/ECI/04028/2013), Instituto Superior Técnico, University of Lisbon, Portugal

Abstract

It is presented an overview of observations of features related to water-stone interactions in contemporary works of the built environment at several Portuguese locations, aiming to assess their relative importance and discuss their relation to engineering and architectural options.

Peer-review under responsibility of the organizing committee of WRI-15
Keywords: geologic materials, alteration processes, built environment, natural stone

1. Introduction

Stones used in the built environment are exposed to several alterations processes[1] promoted by meteoric water (in the usual sense of water with an atmospheric origin). In that sense, water-rock interaction studies can be extended to the built environment to understand the susceptibility of building materials under their onsite application conditions. But this extension needs to consider specific conditions related to engineering and architectural options. This perspective concerns diverse kind of works, from major public engineering works to domestic environments. In this context, there is interest in understanding processes related to water related alteration processes as their impact could be addressed through moisture management. In the built environment, even situations where water-rock interaction is mostly limited to stone surface (as biological colonization and surface deposition) can have an important visual impact with deleterious effects.

In this work, based on our experience, we attempt a synthesis of observed features related to water-stone interaction in the built environment considering their implications in relation to processes characterization (since they allow the observation of the earlier stages) but also in terms of architectural and engineering options for new

* Corresponding author. Tel.: 351253604300.
E-mail address: casaix@dct.uminho.pt

Peer-review under responsibility of the organizing committee of WRI-15
doi:10.1016/j.proeps.2016.12.081

and old constructions. While our focus (and our experience) concerns mainly natural stone, the features considered extend to other inorganic porous materials such as mortar and the processes can affect other materials, such as paints, as well.

2. Materials and methods

The results discussed below were obtained by macroscopic field observations in contemporary built works of diverse towns of Portugal. One can consider diverse types of products of the interaction of meteoric water with building materials and detailed proposals and discussions can be found in[2] and references therein. However, in this publication, we will consider two main groups: i) stains (a term used here in a very wide sense for transformation features where the loss of matter is negligible and there could be even addition of matter); ii) erosive features (with loss of material). Occasionally, field macroscopic observations were complemented by laboratory studies by scanning electron microscopy for textural observations and identification of neoformations.

3. Stains

As referred to above, the term stains will be used for alteration features that do not mark significant loss of material (but the processes that caused the stains can contribute to erosive processes). Stains related to biological colonization and soiling (one is going to consider them together as it is not always easy to tell them apart macroscopically) are generalized in outdoor situations and can affect all kind of built elements. They can occur on different substrates, even on rocks with very low porosity such as grayish unweathered granite (Fig. 1a), depending mostly on the moisture conditions. Sometimes biostains show very heterogeneous distributions related to moisture zones as joints between stones or to specific architectural details (Fig. 1b) while other times can have a widespread distribution on surfaces such as whole portions of north façades. Hence, these stains show patterns related to moisture presence and can be used the other way around, as markers of moisture conditions. The visual degradation impact can be considered to be higher on light colored stones (being more conspicuous). Moisture stains are observed in stones with an impermeable surface and their distinction in relation to soiling is not always easy. Carbonate stains are not as generalized as biological colonization, since they seem to be related to more specific circumstances of water-materials (cement) interaction[3], but, nonetheless, they are very frequent on different kinds of contemporary works and could be found also in sheltered sites such as underground subway stations[4] and parking lots. As they are related to precipitation from flowing solutions, they can also be considered markers of the pathways of those solutions and evidences of masonry defects[4] and they tend to occur associated with solutions pathways such as joints or fissures (Fig. 1c). However, there are also carbonate deposits on large areas as for example in stairs, showing flooding-like distributions. There are observations[3] that point to a recurrent process of formation, at least in some instances, indicating a possible persistent source that is still active (and not limited to the initial instances of mortar application). Their visual impact could depend on the colour of the affected materials as they are more conspicuous when occurring over darkish materials. While their effect on the stones is one of staining and coating, we admit that the processes in their genesis could contribute to loss of pieces as seen in Fig. 1d. Salt efflorescences are related to water mobilization of salts and their crystallization by drying. Hence they tend to occur on sheltered locations that avoid the effects of leaching. They are very frequent in situations of painted walls where there is water infiltration and, in that situation, they can cause marked paint erosion (Fig. 1e) and even affect the mortar. They can be observed also in other locations such as staircase landings (Fig. 1f) to bathroom floors (Fig. 1g). In these constructions efflorescences, alkaline salts (in the sense, usually used in the Earth Sciences, of compound of an alkaline metal), mostly sodium sulfate, are dominant but other salts such as alkaline nitrates and calcium and magnesium sulfates have also been found[5]. It has been referred that alkaline soluble salts can promote limestone staining[6] and darkish stains have been observed in association with soluble salts. There are other, rarer, stains such as those related to sulfide oxidation (Fig. 1h) linked to a specific rock characteristic (they might be associated with some localized erosive effect, but it must be noted that, in at least one case, soluble sulfates have been identified associated with these stains[7]). There are also some instances of stains related to metals alteration products over stone surfaces. Other extremely rarer occurrences concern gypsum-rich black crusts[5] (which seem to highlight the chemical susceptibility of limestones to the environment pollution) and silica stains (whose genesis is still unclear, namely in terms of the dominant source[5]).

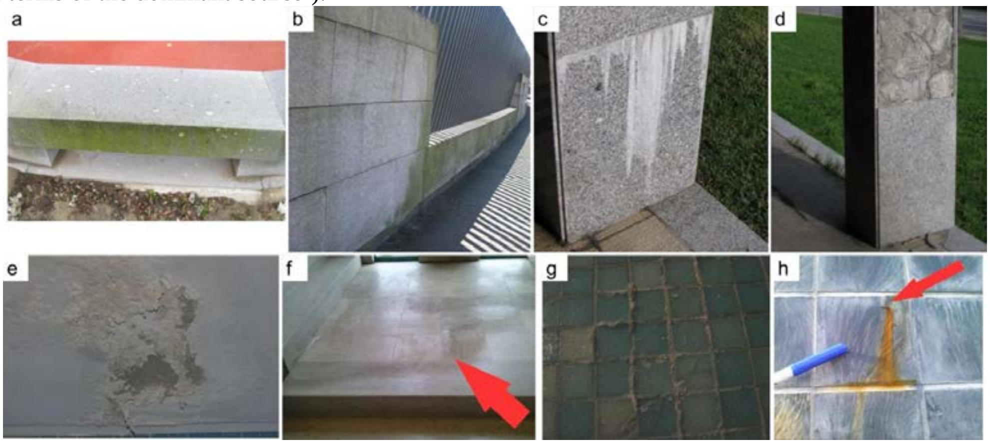

Fig. 1. Examples of stains: a) greenish biostains on grayish granite in a public park stone bench; b) greenish biostains on wall (marking moisture patterns related to architectural characteristics); c) whitish carbonate stains marking solutions descending flow from joint; d) failed stone cladding in the same building complex than previous image; e) salt efflorescences on ceiling causing paint erosion; f) salt efflorescences on a staircase landing on limestone (indicated by red arrow); g) salt efflorescences on bathroom floors; h) rust-like stains attributed to sulfide oxidation (note how the stain crosses the joint between stone tiles and also note the slight erosive feature - red arrow).

4. Erosive features

The most intense and widespread erosive features found in our studies in connection with the effects of solutions were in porous limestones similar to the ones our team has studied in salt laboratory weathering experiments[8,9] in a underground subway station of the Lisbon Metro near the Tagus River and associated with the occurrence of salt efflorescences[4]. There were also some intense erosive occurrences, also in porous limestones, in building façades near the shore (but with a more spot-like distribution, possibly indicating the effect of variations of properties on the stone) as illustrated in Fig. 2a and in schists (in the general sense used in[10]) in a porch structure (Fig. 2b). Other erosive occurrences were found associated with soluble salts, especially in porous limestones affected by capillary rising solutions. As referred to above, there are also some rare occurrences where sulfide oxidation leads to punctual erosion of oxidized portions (see Fig. 1h). There are also other erosive features (for example in rocks applied in floors[11]) but there is no clear evidence of their relation to water-rock interaction.

5. Final considerations

While its effects are, macroscopically, limited to purely visual alterations with negligible erosive impact, biological colonization spread and the extension of its occurrences makes this the number one problem in terms of visual degradation of contemporary construction works. The second most important issue (also with a visual impact) concerns carbonate stains that occur regardless of stone characteristics. The distribution and recurrence of carbonate depositions suggest their association with materials-water interaction and their consideration as a generalized hazard associated with the alteration of cement materials. On the other extreme, sulfide oxidation stains are related to specific characteristics of rocks that can be avoided through petrological studies. In relation to moisture stains, they are related to the presence of pores in rocks but also to stone surface treatment. The issue is less clear in relation to other referred stains: in the case of biological colonization and soiling, the main promoting agents are exogenous but while the stains are observed in all kind of rocks with different weathering degree it seems that porosity could be an important promoting factor. The same issue could be considered for salt efflorescences and black crusts, adding, in the last case, a possible impact of chemical susceptibility and contribution from the rock (it seems that carbonate rocks will be more susceptible to black crusts in the short term). The question of silica stains is a more complex one given the scarcity of occurrences and it is unclear at the present time what it is the rock contribution.

Fig. 2. Erosive features on (a) porous limestones and (b) schist rocks on a porch-like structure (erosion concentrated along joints suggesting solutions circulation).

Erosive features are mostly related to situations where the action of soluble salts is suspected and can be related to circulation of salt solutions and salt crystallization. Soluble salts were observed to be, clearly, the main and most widespread erosive agents affecting contemporary constructions. The collected observations suggest that there is a common salt contamination hazard associated with water-materials interaction whenever water is allowed in contact with materials both outdoors and indoors, by capillary rising or infiltrations related to structures defects. Erosive features seem to affect mainly porous limestones and schists, possibly highlighting features that promote stone susceptibility to salt weathering. The observation of contemporary building works seems to be a very relevant way to understand the effects of weathering processes. While we see no reason to believe otherwise, it will be necessary to extend these studies to contemporary constructions of other countries to confirm the frequency of these alteration features, namely in relation to carbonate stains and salt weathering, as well as the possible relations between biological colonization and climatic conditions.

Acknowledgements

The Fundação para a Ciência e Tecnologia supports the Lab2PT, Landscape, Heritage and Territory Laboratory (UID/ECI/04028/2013, funds from Portuguese Republic and European Union, FEDER, Programa Operacional Factores de Competitividade – COMPETE 2020 – Programa Operacional Competitividade e Internacionalização, POCI, POCI-01-0145-FEDER-007528) and the CERENA - Centro de Recursos Naturais e Ambiente (UID/ECI/04028/2013, Portuguese funds).

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