Salt weathering processes of reconstituted stone used in the Orval Abbey (Belgium)

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Abstract

In its present state, the Orval Abbey, in southern Belgium (49.64°N, 5.35°E), comprises two parts. The mediaeval part, which is currently in the state of ruins, was built in Bajocian and Sinemurian limestones of local origin. The Sinemurian stone (SN) is a siliceous limestone with a low total porosity (7.6 ±0.2%) with no clearly dominant pore access radius. The Bajocian limestone (BJ) has a higher total porosity (31.1±0.7%) with pore access thresholds at 0.5 and 12 µm.

The modern part of the Abbey was built from 1926 to 1948, on the foundations of buildings dating from the late 18th century that have been destroyed in the meantime. A reconstituted stone (RS) was produced during the last major building phase (1933-1948), and used in complement to the natural stones mentioned above. Although the production process is not known, microscopic observations and chemical analyses are consistent with the very scarce historical archives and have shown that the RS was made from a mixture of crushed fragments of both natural stones and cement [1].

The RS is highly susceptible to salt weathering, whereas the natural stones not. The aim of this study is to assess these damage phenomena.

Earlier results have shown that some physical characteristics of the RS are in-between those of both natural stones, whereas others are very close to those of the BJ. Chemical analyses, however, have shown that the RS, even in an un-weathered state, contains sulphur minerals that may constitute a source of salts within the stone itself.

Keywords: salt weathering, thermography, reconstituted stone

Mapping of salts in a weathered zone

Soluble-salt and moisture content of drilled samples

Stone powder samples have been collected by means of drilling (diameter 5 mm) on a damaged wall made of RS (Figure 1). Samples were lifted beneath (at 2, 10 and 19 cm height) and above (at 22 and 42 cm) a weathering fringe visible at a height of approximately 20 cm. The uppermost point was selected reasonably far from the fringe in order to serve as a reference for un-weathered material.

A quantity of 100 mg of stone powder was poured into 500 ml of distilled water for 24 h in order to ensure complete dissolution of soluble salts. The concentration in salts was determined by ion chromatography (DIONEX ICS 2000, for anions) and ICP-OES (Thermo ICAP 6000, for cations). The highest concentrations were observed for the samples just below and just above the weathering fringe.

Mapping of salts by means of portable X-ray fluorescence

Measurements of the elemental composition of the outer surface were carried out by means of a portable X-ray fluorescence (pXRF) device (Thermo Niton XL3t), at the same heights where drilled samples were lifted. The results (Figure 1) indicated a clear increase of the concentration in sulphur (S) when moving from the un-weathered zone to the weathered one. The values obtained at a height of 22 cm, slightly above the weathering fringe, were higher than those for the reference point, suggesting that salt damage will likely progress upwards.

Infrared thermography

Passive and active infrared thermography (IRT) images of the same test zone were acquired. A thermo signal (TS) image can be interpreted in terms of surface temperature, although the emissivity plays an important role. The obtained TS-images confirmed (Figure 1) that a thermal gradient exists over the zone before flash illumination, likely related to a moisture content gradient. Images acquired during flash illumination (either with or without subtraction of the initial TS) revealed a different thermal response in a zone that is not weathered macroscopically but enriched in salts, according to results of IC analyses of aqueous extracts of drilled samples and pXRF measurements.

Laboratory experiments

Time-release of ions through aqueous extraction

Un-weathered samples of the three types of stone (approximately 19 g of each) were poured into 50 ml of demineralized water. Samples of the aqueous solution were collected at different time intervals up to 48 h. The concentration in Cl^- and SO_4^{2-} was measured by IC.

For all types of stone, a continuous release of salts was observed

Continuous evaporation experiment

A continuous evaporation experiment was conducted by ensuring continuous supply of water through the bottom face of a RS core (3.5x7 cm) and evaporation of water through the upper face (for 54 days).

Surface colorimetric measurements revealed a progressive change of the colour of the stone, more precisely the development of a yellowish ring and whitening of the surface.

At the end of the experiment, the core was sawn longitudinally to allow for a pXRF study of the variations in the elemental composition. A clear gradient in the elemental concentration of S was observed. This showed that sulphur migrates within the RS together with the flow of water and accumulates near the evaporation surface.

Conclusions

On-site measurements with infrared thermography and a portable X-ray fluorescence device offer an easy and handsome way to characterize salt accumulation, even at stages when no damage is visible.

The laboratory results have shown that the weathering of the RS is due to mobilization of salts that are present within the stone itself, and that can be easily mobilized by water. To date, analyses revealed that sulphur-containing minerals are present in the reconstituted stone and are likely the source of the sulphate observed (thenardite, gypsum). However, the source of the cations, especially Na^+, is not known yet.

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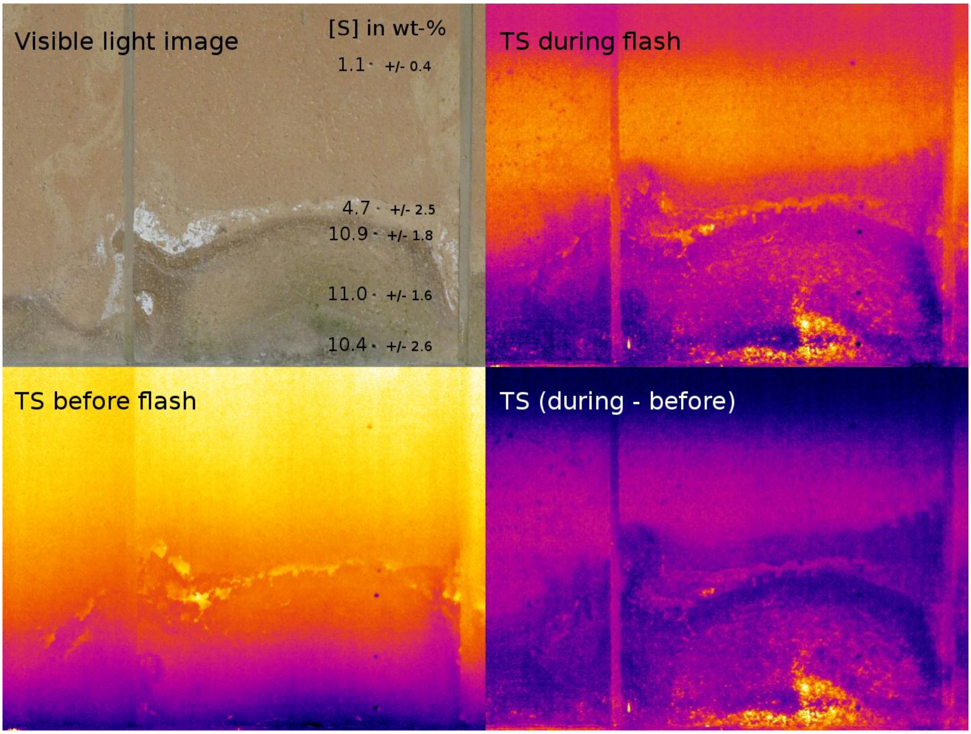

Figure 1: Weathered zone of a reconstituted-stone wall. Mapping of S obtained from pXRF (expressed in weight percent); thermal image obtained before flash illumination revealing a bottom-to-top increase of surface temperature; thermal image obtained during flash illumination revealing a thermo signal response extending further than what is visible to the naked eye; subtractive image enhancing the contrast between salt-rich and salt-poor zones.

Reference

[1] Thomachot-Schneider C., Gommeaux M., Fronteau G., Oguchi C.T., Eyssautier S. & Kartheuser B.; A comparison of the properties and salt weathering susceptibility of natural and reconstituted stones of the Orval Abbey (Belgium); Environmental Earth Sciences, (63), issue 7-8, (2011), 1447-1461.