

## Thermal response of building stones contaminated with salts

\*Norman Sandy Dominique LELARGE<sup>1</sup>, Celine Elise Thomachot-Schneider<sup>1</sup>, Kamel Mouhoubi<sup>1</sup>, Jean-Luc Bodnar<sup>1</sup>, Patricia Vazquez<sup>1</sup>

1. University of Reims

Salt crystallization is a weathering process encountered in building stones. Salts appear inside the building stones mostly before to the beginning of the degradation. Therefore, it becomes necessary to detect these salts before an irreversible decay occurs. Currently, the existing portable and non-destructive methods used in cultural heritage do not identify the salt composition nor quantify their concentration. Thus, a new tool or protocol is required to advance in the characterization of salts within stones in the field.

Infrared Thermography (IRT) is a well-known and non-destructive technique (NDT) used in a passive way to detect salt presence linked to moisture and their resulting decay forms. To understand the stone behavior under salt crystallization and to predict its evolution, the active IRT was tested. The main objective was to trial this technique in order to obtain more information such as the type of salt, its precise location and its concentration.

Three building stones were studied: two natural limestones (Bajocian (BJ) and Sinemurian (SN)) and a reconstituted stone (RS) made with debris of these limestones. These three materials were used simultaneously in buildings of South of Wallony (Belgium) as their color and origin are close to each other. Forty-five disk-shaped samples of each stone were submitted to immersion/drying tests in water (used as reference) and in salt solutions of  $\text{Na}_2\text{SO}_4$ ,  $\text{NaCl}$  and  $\text{MgSO}_4$  at 7%, 14% and 26% in weight during 20 cycles. The weight of the samples and the surface color were recorded after each cycle. After 1, 5, 10 and 15 cycles, 3 samples were taken out for active IRT measurements.

Active IRT was conducted by means of a FLIR infrared thermography camera SC655 with two flash lights placed at 45° of the sample, symmetrically along the axis of the camera, producing a light of 4800 J for 5 ms. The flux of photons emitted by the flash excited the sample leading to an increase of its temperature, and the corresponding thermosignal was recorded by the camera. The thermosignal (TS) depends on i) the mineralogical composition and the physical parameters of the material: density, porosity and pore structure, specific heat, emissivity, conductivity and diffusivity, ii) the surface properties (roughness, color). Thermosignal (TS) images were recorded and thermal curves over time were extracted from them. Macroscopic observations showed that all the stones developed efflorescences on their surface with different morphology depending on the type of salts. Only BJ and RS, the most porous stones, showed a notable sanding starting from cycle 10.

Colorimetry showed that  $\text{Na}_2\text{SO}_4$  efflorescences tended to enlighten the different stones whereas  $\text{NaCl}$  and  $\text{MgSO}_4$  darkened them. Weight increase of the samples was different depending on the stones and the salts properties. But the overall tendency revealed that the most concentrated the solution was, the most the weight increased.

To avoid the influence of color in the IRT response, the samples were black painted before the IRT analysis. For the most porous stones (BJ, RS), the TS depended on the salt concentration and the number of cycles. The  $\text{Na}_2\text{SO}_4$  contaminated samples had the highest TS compared to  $\text{MgSO}_4$  and  $\text{NaCl}$  that were similar and close to the initial TS. Especially for the  $\text{Na}_2\text{SO}_4$ , the TS increased with the concentration. It also increased with cycles until the beginning of sanding and cracking (cycle 10). After that, TS decreased and stabilized to the initial value. On the least porous stone (SN), no change of the TS was observed in relation to the salt type, the concentration or the cycle number.

The active IRT seemed to be a non-destructive technique adapted to identify and quantify the salts.

Though, it is necessary to use it during the first' s states of salt accumulation. Further tests will used longer heating of the samples thanks to halogen or ceramic lamps in order to have a deeper thermal response of the sample.

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