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Spontaneous electrical effects in masonry affected by capillary water rise: The role of salts

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HIGHLIGHTS

- ▶ One-brick-thick masonry model was built with fired clay bricks.
- ▶ A steady-state capillary flux of water with chloride and sulphate was attained.
- ▶ Moisture, salts and spontaneous potential were measured at different heights.
- ▶ The role of salts was highlighted.
- ▶ The results are consistent with the electrical double layer theory.

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ABSTRACT

The investigation of the electrical effects accompanying capillary water rise from ground in old masonries is of great practical interest, as such effects might be exploited for both measurement purposes (determination of moisture and soluble salts) and for dehumidification purposes (techniques based on electrokinetic principles).

In the present paper, the spontaneous dc voltages arising in a real-scale masonry model subject to a steady-state capillary flux of saline solutions (0.05 M sodium chloride and 0.05 M sodium sulphate in water) were measured. The resulting voltage depends on the amount and distribution of salts, rather than on moisture content in the masonry.

1. Introduction

Capillary water rise is one of the main and most diffused problems affecting old masonry walls [1], as it causes materials degradation [2], as well as hygienic and safety concerns for the building users [3]. The presence of moisture in historic structures is among the causes responsible for the emptying of old town centres and rural buildings, with great damage for local cultural identity. Thus, the investigation of capillary water rise in masonry walls, especially in terms of degradation mechanisms, measurement techniques and remediation systems, is of paramount importance and still requires a strong research effort [4].

In particular, the current techniques for the dehumidification of old masonries are often not fully satisfactory due to several reasons (invasiveness, scarce effectiveness, poor long-term performance, bad aesthetic impact, etc.) and some promising results were shown by systems based on electrokinetic principles [5]. The occurrence of electrical effects in moist masonry walls is due to the electrical double layer arising at the water/solid interface in moist porous building materials [6]: when capillary water flux is present, e.g. from ground in the case of masonry, a spontaneous potential (streaming potential) takes place [7]. Nevertheless, the information on the electrokinetic phenomena occurring on site, in actual masonry walls, are still very scarce [8] and a better knowledge of them could enhance the development of more reliable dehumidification systems and might also be exploited for on-site measurement of moisture and salts. For example, dehumidification systems based on electro-osmosis are usually applied to masonry without any preliminary investigation on the existing spontaneous potential and with no subsequent monitoring (except for the current consumed by the system, which however is not indicative of the actual dehumidification along the entire height of the wall), with strong prejudice for their real effectiveness. Moreover, the measurement of electrokinetic phenomena connected with rising moisture and salts might be a further tool for the smart monitoring of historic

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structures, which are often affected by dampness. As a matter of fact, the issue of smart monitoring of masonry buildings has raised strong interest in recent years [9–11].

In this paper, the spontaneous potential occurring in masonry due to capillary rise of salts-contaminated water is investigated, by means of an experimental masonry model. The focus is on the role of soluble salts in the final spontaneous potential. Sodium chloride and sodium sulphate were chosen for the experimental survey, as they are the most common salts in historic building walls [12,13].

2. Background and research aims

In a previous paper, a reliable methodology for monitoring moisture, salts and bias voltage in masonry walls was presented, taking advantage of some purposely designed experimental fixtures [14]. The fixtures are real-scale masonry models (25 × 63 × 105 cm^3), where ground brick is used for the joints instead of mortar, in order to enhance capillary suction. Capillary rise is provided by a constant height (3 cm) of deionised water lapping the bottom of the masonry models.

Not negligible spontaneous potentials were detected and their values appeared related mainly to the small amount of salts originally contained in the bricks (and driven along the capillary path by rising water) rather than to the amount of moisture [14]. For this reason, in the present paper, the role of soluble salts on the final spontaneous potential is investigated by means of the same kind of experimental fixture: chlorides and sulphates were added to rising water, in order to reproduce the state of actual masonries, where water from ground usually carries on various kind of salts, responsible for the well-known efflorescence (i.e. crystallisation on the surface) and subflorescence (i.e. crystallisation below the surface) [15].

At the end of the paper, a comparison will be made with the results of the previous investigation [14], where a masonry model made with the same batch of bricks and having the same size had been built, but deionised water had been used for the capillary suction instead of saline solution.

3. Materials and methods

3.1. Bricks and experimental masonry models

Commercial fired-clay bricks 25 × 12 × 5.5 cm^3 (RDB, Pontenure, Italy) were used for the construction of a one-brick-thick masonry model (25 × 63 × 105 cm^3), according to the scheme in Fig. 1. As mentioned above, a 3 mm layer of brick powder (obtained by milling some bricks from the same batch to a grain size <63 μm) was put among the bricks, instead of conventional mortar joints, in order to: (i) enhance the capillary suction (due to the larger capillary suction ability of fine powder respect to mortars), and (ii) take into account only the role of bricks in the final electrokinetic effects.

The bricks used are averagely characterised by total porosity 34.9% and pore mean size 2.47 μm (determined by mercury intrusion Porosimeter 2000 Carlo Erba with a Fisons Macropore Unit 120). Their mean soluble salts amount was determined by extraction with deionised boiling water (electrical conductivity <0.02 μS), filtration by blue ribbon filter and final ion chromatography (Dionex ICS-1000; anion-exchange column kept at 30 °C; measuring cell temperature 35 °C) and resulted the following: $Cl^- = 0.017$ wt.%, $SO_4^{2-} = 0.021$ wt.%.

3.2. Conditioning procedure

The masonry model was kept at room conditions (T = 21–24 °C, RH = 30–50%) and was subjected to continuous capillary suction by keeping its bottom under a constant 3 cm head of saline solution (0.05 M NaCl, 0.05 M Na_2SO_4). Chlorides and sulphates were chosen as they are the most diffused salts in ancient masonry walls [13,16,17].

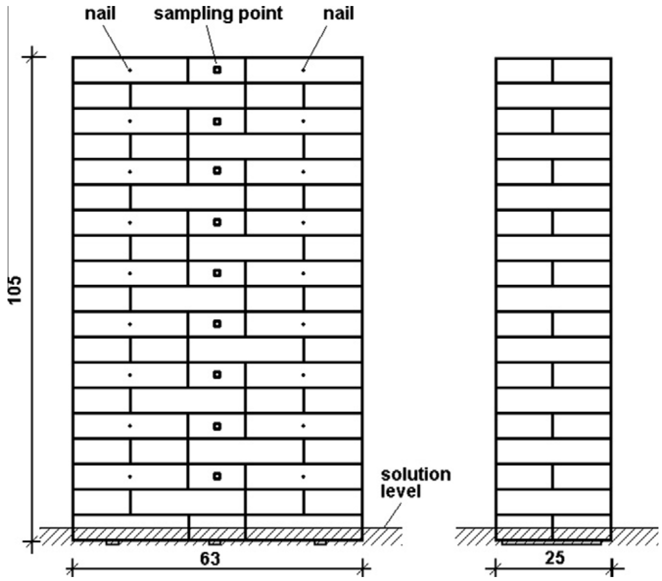

Fig. 1. Masonry model used for the investigation (sizes in cm).

3.3. Testing

Permanent sampling points for the measurement of moisture/salts and electrodes for the measurement of electrical potential were set at different heights in the masonry, in the positions shown in Fig. 1. According to the measuring methodology described in [2,18], moisture and salts were measured in permanent sampling holes, where brick fragments (taken by chisel from the same brick where each hole was drilled) were placed and sealed. The fragments were periodically used for the determination of moisture (by oven drying at 100 ± 2 °C) and soluble salts (by ion chromatography, according to the procedure described in Section 3.1).

For the measurement of the electrical potential, the procedure described in [14] was followed. Electrical potential was measured close to the permanent sampling points (on the right and on the left respectively) by stainless steel nails ($\varnothing = 2.1$ mm) fixed about 2 cm deep into previously drilled holes in the bricks, with a nickel-based conductive paste. The electrical potential in each nail was measured by a high impedance (10^{14} Ω) Keithley Electrometer 602 (accuracy ±10^{-5} V) referred to earth; the water at the bottom of the masonry was earthed as well, by keeping an earth-connected stainless steel plate permanently immersed in the tank. The electrical potential at each height was obtained averaging the values of the two nails (one on the right and one on the left of the sampling hole used for moisture and salts determination).

Moisture was measured 60, 90, 120 and 150 days after pouring the saline solution into the tank. After 150 days, when a steady-state capillary flux was certainly attained (Section 4.1), salts and electrical potential were measured as well.

4. Results and discussion

4.1. Moisture

The moisture detected in the masonry at 60, 90, 120 and 150 days is reported in Fig. 2, where a progressive decrease in the moisture amount with height, which is typical of actual masonries, can be observed. The slight increase in moisture in the bottom part of the masonry can be ascribed to a progressive filling of the finest pores of the bricks, taking longer time than the large ones. At 150 days, a steady-state capillary flux was considered as attained.

4.2. Salts

At the end of the experimental campaign, the masonry was characterised by evident white efflorescence (Fig. 3). Remarkably, efflorescence were located mainly at a height of about 20–50 cm, where the amount of moisture in the bricks makes the salts crystallise on the external surfaces. Conversely, in the upper part of the masonry, where lower moisture amount is present, the