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Does electro-osmosis work in moisture damage prevention? Applicability of infrared-based methods to verify water distribution under electric fields

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ABSTRACT

In the recent years electro-osmosis drying devices applied to walls in both modern and historic masonry has become one of the leading innovative techniques to prevent damages caused by capillary rising water in building materials. Since the scientific community is raising many doubts on these techniques, the authors aim to propose a fast, simple, noninvasive and economic method to evaluate the dehumidification process specimens of the most used building materials. The paper presents a procedure to monitor water content in different specimens of the most used building materials (e.g. brick, mortar and plaster) and verify any kind of possible effect of electro-osmosis on water diffusion, above all drying kinetic. The procedure is based on the measure of water content and drying behaviour with and without the application of electrostatic fields with the traditional gravimetric method, infrared thermography and optical reflectance in the 940–980 nm with a high sensitivity avalanche photodiode. This allowed us to visualize the surface water content gradient of different building materials. Using different voltage values between tow electrodes coupled with the material under examination, we observed no variation in water distribution inside the material nor any difference in evaporation phenomena. For strong electric field values (V > 150 V/m), compared to those normally used in electro-osmosis dehumidification, we measured mainly the heating caused by the Joule effect due to the intrinsic ion's distribution inside the material.

1. Introduction

Many degradation phenomena affecting buildings materials like freeze-thaw cycles [1], mechanical behaviour weakness [2] salt decay processes [3,4], biodeterioration [5] and health problems [6] are driven by the presence of water in porous materials. Moisture can be conveyed inside building materials by many different processes such as vapour condensation, direct exposure to meteorological events, capillary rise, accidental leakage of conducts and operating humidity. Rising damp is one of the main causes of wetness in buildings and a widespread problem affecting both modern and historical construction. It is related to the capillary suction exerted by porous materials on groundwater and surface water that slowly penetrate inside a wall. Capillary suction of groundwater and rainfall percolation is much more efficient than condensation in causing dampness [7]. Its dynamics primarily depends on the thickness of the wall, the sorptivity of the materials and the evaporation potential at the materials' interface [8]. The absorption and transport of water inside a porous medium is a complex mechanism, which involves multiple phases and various driving processes [9]. Although many studies are carried out, the reliable procedure for rising damp removal is still a problem. The scarce knowledge of the involved mechanisms hinders the resolutions procedures. Among the multitude of dehumidification and reconditioning methods, the electro-osmotic treatments effectiveness is controversial [10,11]. Electro-osmosis is successfully applied in the consolidation of soils for many years [12–14] and in other fields of study [15]. Despite its application on the dehumidification of buildings is quite widespread and documented many doubts arises in the scientific community, for example in [16]. In a recent study, Franzoni pointed out one of the core problems in the study of dehumidification processes against rising damp: the need of an accurate and quantitative evaluation of water presence in the materials and the effectiveness of the treatments [17]. One parameter suited to identify the amount of free water inside a porous material is the moisture content (MC). It is defined as the percentage ratio between

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Table 1
Specimens used in trial 1.

Specimen	Dimensions (cm)	Dry density (g/cm^3)	Saturated density (g/cm^3)	MC at saturation (%)
T1	15.4 × 7.2 × 0.7	2.62	2.72	3.96
T2	15.4 × 7.2 × 0.7	2.64	2.76	4.69
P1	23.3 × 3 × 1.6	1.46	1.79	22.72
P2	19.5 × 3.3 × 1.9	1.41	1.74	22.82

the mass of water inside a material (m_w) and the mass of the dry specimen (m_d):

$$MC = \frac{m_w}{m_d} 100 \quad (1)$$

Measuring the moisture content and moisture content distribution of building materials in the easiest, cheapest and least-invasive way possible is indeed a fundamental key of the dehumidification process and still an open challenge [18]. Uncontrolled factors as non-homogeneous density, porosity, chemical reactions, surface treatments and weathering, salts presence, mould and insect damage affect many existing noninvasive methods, above all in historic buildings [19]. The most accurate methodology is oven-dry gravimetry that is an absolute, precise and repeatable measure nevertheless it is invasive and destructive and this is a great problem in culturally valuable constructions. The paper presents the study on the effectiveness of electro-osmosis treatments monitoring the drying behaviour of different laboratory specimens. This is achieved by means of infrared thermography, gravimetry and an innovative optical reflectance technique. Those methodologies allow us to identify possible variations in moisture diffusion in presence and absence of a direct current applied on the different specimens.

Electro-osmosis principles: Active electro-osmotic dehumidification systems are based on the electrokinetic effects, caused by the application of a direct current in a saturated porous system and the resulting water migration processes inside pores and capillaries. Helmholtz, Gouy-Chapman, Stern and Grahame theories [20,21] explained that the electro-osmotic flow is due to the formation of an electrical double-layer at the interface of the solid's pore system and the water solution (electrolyte). The electrical double-layer is due to the spontaneous charging of a solid surface interacting with an electrolytic solution. The solid surface influences all charged and polar species in solution. Ions with a charge opposite to that of the solid system (counter-ions) are attracted by the solid surface and their concentration would be grater in proximity of the liquid-solid interface. Ions with the same surface charge (co-ions) arranges consequently far from the solid surface until a steady state condition is reached. In masonries affected by rising damp, a spontaneous electrical potential (streaming potential) is generated [22]. Ordinarily internal surface of pores and capillaries of building materials is negative charged [23]. To obtain the potential difference between wall and ground the electrodes are placed in both sides. Usually inside the wall is installed the positive pole and in the ground the negative pole. Under the application of an external electric field the ions accumulated in the electrical double-layer tend to restore the electro-neutrality of the system, moving towards the negative electrode dragging also the nearby ions and the coordinated water molecules [24]. The resulting transport of water is related to the intensity of the voltage gradient, to the properties of porous material (i.e. geometry of the pores and capillaries, solid's chemical composition) and to the chemical composition of the water solution itself [11]. Scientific community is doubtful about the reliable effectiveness of those methods since the clear role of the electro-osmosis in the dehumidification process of real buildings is controversial and not well-documented [17].

2. Materials and methods

2.1. Trial 1

First step was the comparison between two ceramic tiles and two cement-lime plaster specimens (Table 1), saturated with deionized water. Measurement of MC, reflectance and infrared thermography were done during the drying process inside a climatic room for 53 hours. Two of the specimens are observed in an electrical field and the other two far enough between insulating media (cardboard and PVC). The experiment was conducted inside a climatic room to ensure constant environmental condition, since water migration processes are influenced by microclimate.

2.2. Gravimetry

Gravimetric water content was measured by means of a Kern EW 1500-2 M balance with an accuracy of 0.01 g according to the standard UNI 40/93. Moisture content (MC) and saturation grade (SG) were calculated as follows:

$$MC = \frac{m_m - m_d}{m_d} 100 \quad (2)$$

$$SG = \frac{m_m - m_d}{m_{w,sat} - m_d} 100 \quad (3)$$

m_m is the mass of the specimen weighted at different moisture content, m_d ($w_{c,rel}$ = 0%) is the dry mass and $m_{w,sat}$ ($w_{c,rel}$ = 100%) is the saturated mass.

2.3. Infrared thermography

Infrared thermography (IRT) is a well-established technique, which is used for years to qualitatively map the moisture accumulated on and within building structures [25–28]. This approach combines a non-contact, non-destructive testing technique with excellent resolution over a wide range of temperatures due to the optical nature of IRT. This tool is extremely useful because of the rich information of the thermographic images, which allows to localize the spatial distribution of wet areas. In fact, the temperature of damp areas may be lower than that of dryer areas due to surface evaporation, or the temperature may be higher due to the higher thermal inertia of water compared to the dry building materials. For this reason, qualitative tests are sometimes unreliable. In addition, IRT investigates only the amount of water within a thin surface layer, and the technique can be used to rapidly survey large surfaces, allowing repeated measurements through time. For example, it is useful to monitor the phenomenon of water rising from the ground. The near-infrared imaging has a similar approach that allows to detect water in the bandwidth of 1000 nm to 2500 nm to detect water due to its very strong absorption band at approximately 1940 nm and less intense at 970 nm, 1140 nm and 1450 nm. It is interesting to measure evaporative flux to evaluate the effects of moisture on degradation phenomena occurring in building structures [29]. This approach does not measure directly the moisture content. Instead, it gives an estimation of the evaporative flux that depends also on materials properties (firstly porosity and pore network geometry) and environmental conditions. The possibility to

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