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Moisture diffusion assessment in porous media by IR Thermography

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Abstract

In this work, we propose to monitor the diffusion of water in the porous material, both in time and space by collecting a sequence of IR images, after the application of the contact sponge. The first experimentation was done in situ during a restoration campaign. To improve the understanding of the phenomena, it was planned to carry on some experiments on porous materials that are homogeneous as much as possible. A fired clay brick and a sand stone pietra serena have been used to apply the contact sponge technique and to monitor the induced effects by IRT in a controlled environment.

1. Introduction

The application of InfraRed Thermography (IRT) for the qualitative monitoring of humidity in buildings is reported from the beginning of the use of such instrumentation [1,2]. Water, that is characterized by a high latent heat (> 1 MJ/kg), extracts heat from the surface of the moistened porous material (e.g. bricks, stones, plaster) during its evaporation, generating a decrease of its temperature. Such a temperature decrease is easily monitored by IRT thanks to its imaging and non-contact capabilities. On the other hand, the task to make the qualitative observation a quantitative one is still an open problem [3,4]. The idea to afford the solution of the coupled problem of heat and mass transfer, that is connected with the diffusion of water and the simultaneous diffusion of heat, as a consequence of the perturbation due to the evaporation, is of paramount difficulty. Therefore, some partial, simplified approaches were proposed in the past. One of those simplified approaches, to make quantitative the evaluation of the amount of water contained in the porous materials, is related to the very high heat capacity of water, which significantly changes the thermal inertia of the material that absorbs it. Hence, an active thermography approach is used, that heats the surface of the material by lamps and monitor the increase of temperature of the surface. The surface areas that contain water are supposed to react with a lower increase of temperature in comparison with the drier ones [5,6]. The problem of this technique, that originates from the satellite Remote Sensing of land surfaces, lies on the increase of temperature that makes the evaporation to increase, resulting in a further attenuation of the temperature variation, with an overestimation of the thermal inertia. Other attempts have been proposed to enhance the evaporation effect in such a way to make more evident the presence of water. This is done, e.g. by a controlled forced ventilation [7]. In this case, the increased thermal inertia, due to the water absorbed by the porous material, acts as a dumping effect in the decreasing of temperature due to the evaporation enhanced by the forced ventilation. Recently, the contact sponge method [8,9] is attracting the attention of the restorers and researchers for its easy applicability in situ [10,11]. It consists in applying a humid sponge on the surface of the material in a controlled way. Ludwig et al. [12], proposed to monitor the effect of water evaporation, during and after the application of the contact sponge, by IRT. In this work, we propose to monitor the diffusion of water in the porous material, both in time and space by collecting a sequence of IR images, after the application of the contact sponge. The first experimentation was done in situ during a restoration campaign. To improve the understanding of the phenomena, it was planned to carry on some experiments on porous materials that are homogeneous as much as possible. A fired clay brick and a sand stone pietra serena have been used to apply the contact sponge technique and to monitor the induced effects by IRT in a controlled environment.

2. Materials and methods

The contact sponge method consists of a contact cup that contain the sponge, whose thickness is slightly greater than the height of the cup. The cup containing the humid sponge is pressed manually on the surface of the material until the border of the cup are in contact with the surface. That results in a fairly reproducible action. After a predefined amount of time, for example 90 s, the sponge is removed from the surface and the weight of the sponge itself is compared with that obtained before the application. The difference is the amount of water absorbed by the surface of the material, that can be described by the following equation:

$$W_a = \frac{m_i - m_f}{A \cdot \delta t} \tag{1}$$

where W_a is the water absorbed per unit area and unit time, m_i and m_f are the initial and the final weights of the sponge respectively, A is the area of the sponge and δt is the time during which the sponge and the material remained in contact. Following the application of the sponge, it is possible to monitor the surface by IRT. The area corresponding to the zone of the sponge application is clearly visible due to the strong evaporation effect (see Figure 1). The diffusion of water through the pores of the stones (eventually coupled with the heat conduction as a consequence of the heat sink due to the evaporation) can be monitored as well by collecting a sequence of IR images.

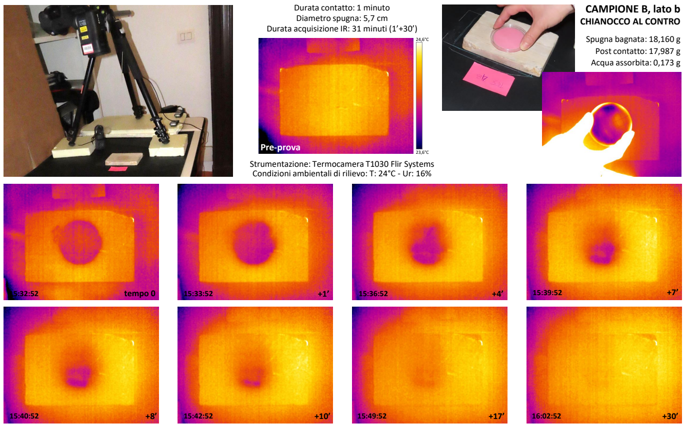

Fig. 1. *IR camera looking at the process of evaporation after the contact sponge application (top left). Application of the contact sponge (top right). Some IR images showing the evolution of the evaporation and diffusion of water in the porous material (middle and bottom rows).*

Being the diffusion of water a process that is ruled by PDE similar to the heat conduction, many solutions available for the heat conduction can be utilized for the water diffusion. We estimate the water diffusivity by using a variant of the thermal diffusivity estimation introduced by Philippi et al. [13].

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