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A new automatic method for continuous measurement of the capillary water absorption of building materials

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HIGHLIGHTS

- This study compares a new technique to measure W_value and saturation coefficient of building materials with conventional methods.
- The new technique can measure the capillary absorption coefficient and saturation coefficient of building materials automatically and continuously.
- The new method is accurate, fast and save efforts.
- The new method is combatable with the conventional methods.

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ABSTRACT

This study compares a new automated technique, developed by the author, with DIN 52617, the conventional technique used to measure the capillary water absorption coefficient (W_value), and with DIN 52620 used to measure the capillary saturation (CS) of building materials. For this study, two different types of stone samples (sandstone from Petra and limestone from northern Jordan) and two types of mortars (air lime mortar and Portland cement (Type A) mortar) were taken into consideration. For comparison reasons, the selection of samples ensured considerable differences in their physical properties. All the samples were measured to determine their W_value and CS by using the conventional technique (DIN 52617 and DIN 52620), then compared to the devised technique. The obtained results showed that there is no significant differences between the two techniques, and thus indicate that the new technique is highly compatible with the DIN 52617 and DIN 52620.

1. Introduction

Among the various agents that are harmful to stone, humidity of different origins is one of the most important. Moisture is associated with most of weathering mechanisms; without water there would be no chemical reactions of stone constituents, soluble salts would not be transported, and there would be no crystallization and recrystallization. In addition, airborne atmospheric pollutants would not be dissolved and transported deep into the stone, so they would not remain in contact with stone constituents for a long time causing little, if any, deterioration [22,23,4,20,14,13,1].

There are different mechanisms that are responsible for the transportation of water and dissolved harmful materials in porous building stones such as direct penetration of rain water, capillary rise, condensation and hygroscopicity. Therefore, water absorption by capillary rise strongly influences the deterioration of porous building materials [10,15,16,24]. The influence of capillary processes on porous building stones is expressed quantitatively by the water absorption coefficient (W-value) and the water penetration coefficient (B-value) [18].

Water enters capillary pores when the attraction to the pores surface is stronger than the water-water attraction. Thus, the efficiency of the suction force depends on the nature of the pores surfaces and diameters. The capillary absorption coefficient is the mass of water absorbed by a test specimen per face area and per square root of time. It is expressed for a porous material based on the Washburn law as:

$$W = \rho\phi\sqrt{\frac{r\gamma cos\theta}{2\eta}}$$

where $\boldsymbol{\rho}$ is the density of the liquid, $\boldsymbol{\eta}$ the viscosity of the liquid, $\boldsymbol{\phi}$ the porosity of the sample, $\mathbf{r}$ the pore radius, $\boldsymbol{\gamma}$ the surface tension of the liquid and $\boldsymbol{\theta}$ is the contact angle [5,12].

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Several techniques can be used to measure the capillary water absorption coefficient of porous building materials, of which the capillary suction test is the most commonly used. This technique is described by many standards such as NBN B14-201: 1973, DIN 52617: 1990, prEN 480-5: 1996, EN 1925: 1999 and prEN 13057: 2000 [7]. In addition, other techniques such as Karsten tube method, Sponge contact method [27], Pipette (micro water drop) method [25] and Digitized micro-tube system [9], can non-destructively be used to measure the capillary water absorption coefficient of porous building materials.

Each of these techniques has its own advantages and disadvantages; the capillary rise test, for example, is a destructive technique as it requires sampling and is time-consuming. On the other hand, this technique is considered the most accurate one to measure the capillary water absorption of porous building materials, which can be attributed to the following factors: i) weight of the measured sample is reported to precision of 0.001 g, and ii) the measurement is performed in the lab so that the climatic conditions (temperature and relative humidity) which *may* affect the results are controlled. Karsten tube has been used for several decades to measure the capillary absorption coefficient of porous building materials in situ; the application of this method possesses further obstacles: i) the tube does not measure the initial water absorption because the first measurement is taken after 5 min, ii) the technique is not easy to handle, and iii) the need for two operators. Due to these obstacles, this method is not very user-friendly [27], [8], Drdácký et al., 2013, [26]. Nevertheless, its most important advantage is that it is nondestructive.

Sponge contact method is relatively a new one, which was developed by Tiano and Pardini to measure the water absorption behavior of porous building materials in 2004. The technique is fast, cheap, non-destructive, and can be conducted in situ or in lab. The major disadvantage of this method is the lack of published comparable results, and the lack of standard procedures [27]. Unfortunately, this method measures only the initial water absorption behavior of the material.

Pipette or micro drop measurement is a nondestructive test used in the field of conservation to measure water absorption behavior of building materials. The test measures the absorption time of a fixed quantity of water on a horizontal surface. Distilled water drop (10 + 2 μl) is dropped from a height of 1 cm above the sample. The time the drop takes to be completely absorbed is then measured ([11], UNESCO/RILEM). This method measures only the initial water absorption behavior of the material, since the limited quantity of water (10 μl) is absorbed by the surface of the tested materials in few seconds. Moreover, the micro water drop method cannot be applied in the field on sun heated or dirty surfaces, neither during direct insolation nor wind [28].

All the above-mentioned methods and techniques used to measure the water absorption behavior of building materials are similar in that they are manual and require a full-time operator during the measurements which may last for a long time. To overcome this disadvantage, Courard and Darimont [6] and Plagge et al. [21] developed an innovative automatic method that registers continuously the variation of mass of the sample immersed into water, from which the capillary water absorption coefficient can be calculated (Fig. 1).

The main difficulty of this method is keeping the water level in which the sample is immersed constantly, which to a certain extent but not completely, is achieved by the movable support. Furthermore, the capillary water absorption coefficient calculated by this technique depends on the weight increase of the sample due to water absorption. However, the weight increase of samples containing salts will be affected by dissolving salts trapped in their pores and their transportation through the water film in contact with the sample. Therefore, their weight will increase due to water absorption but decreases due to salt dissolution and diffusion. This issue may adversely affect the accuracy of measurements [3].

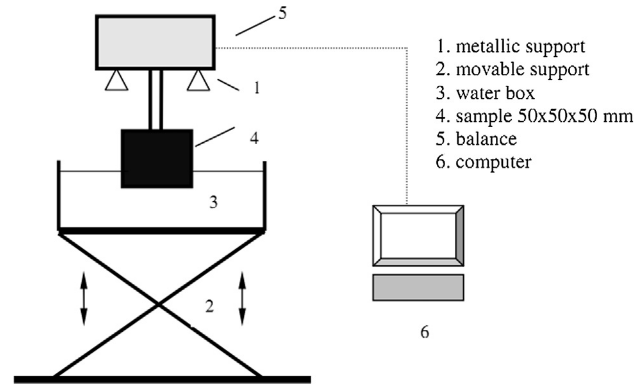

Fig. 1. Setup for automatic measurement water absorption by capillary suction (after Courard and Darimont [6]).

Another innovative technique for water uptake measurement was developed by Drdácký and Slížková [9]; the so called Digitized micro-tube system is based on the ability to make an electronic recording of the data which records the water uptake from the very beginning and makes continuous measurements of water infusion into the surface. The main disadvantage of this technique is that the obtained data covers a very short period of water absorption, due to the limited amount of water in the tube [9].

To overcome the disadvantages of other methods such as weight decrease due to salts dissolution, the manual operation and the short period of measurement, a new automatic technique for the measurement of the capillary water absorption, which does not depend on the weight increase of the sample when absorbing water, was developed by the author. This study aims primarily at testing the compatibility of this technique with conventional techniques.

2. Materials and methods

2.1. Materials

For the purpose of this study, four types of porous building materials, commonly used in Jordan, were taken into consideration. Three sandstone samples from the Disi Sandstone (Ordovician) Formations in Petra and three limestone samples from the Massive Limestone Formation (Upper Cretaceous) exposing in northern Jordan were used in this study. Limestone from this formation was used in constructing many important archaeological structures, e. g. the Decapolis. Furthermore, it is the main source for building stones in modern constructions in Jordan [2].

In addition to sandstone and limestone samples, three air lime mortars with different aggregate/cement mixing ratios; 1:1, 1:2, and 1:3 by volume and three Portland cement (Type 1) mortar with aggregate/cement mixing ratios 1:1, 1:2, and 1:3 by volume were prepared as recommended by Lawrence and Walker [17]. Cylindrical samples with 5.5 cm diameter and a height ranging between 7 and 10 cm were prepared by moulding. The mixture for the air lime-based mortar consisted of 1 part of dry hydrated high calcium lime and 1, 2 or 3 parts of silicate sand by volume using water/lime ratios of 0.7. Mortar samples were de-moulded after 7 days and cured in a controlled environment of 60% RH at 25 °C for 30 days. The same preparation method was applied for the Portland cement-based mortar, with only one difference as the water/Portland cement ratio was 0.5. Some important physical properties of the studied samples are given in Table 1.