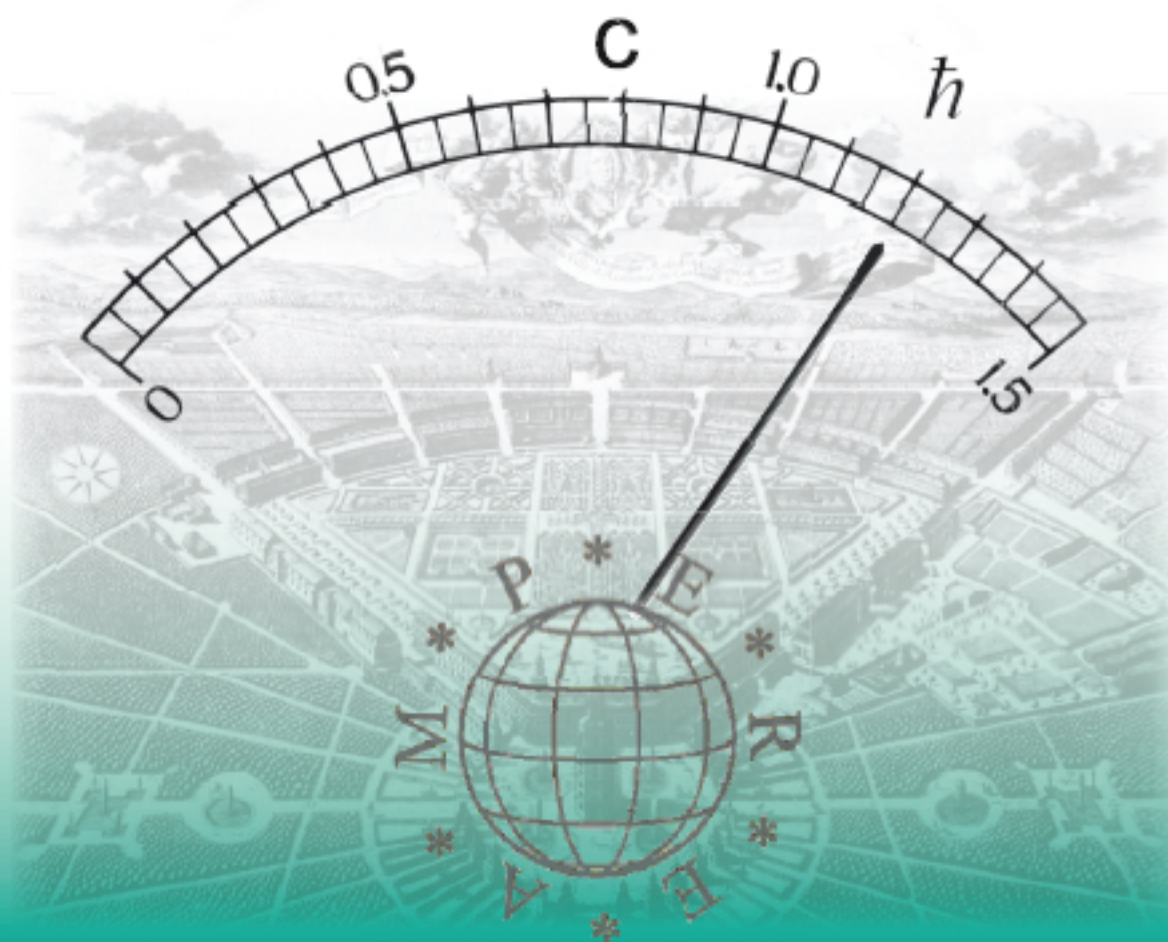


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ATTEMPT TO USE A MICROWAVE MOISTURE MAPPING SYSTEM (MOIST 200B) TO CONTROL AND MONITOR THE WATER UPTAKE OF STONES IN THE FRAME OF CULTURAL HERITAGE CONSERVATION

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It would be highly desirable to be able to monitor the water uptake of a weathered or consolidated stone surface on a building façade, to choose, control and monitor stone conservation treatments. According to the literature a microwave moisture mapping system seemed to be appropriate for these means. In our laboratory study we compared the capillary and adsorption water uptake of five different sandstones measured by gravimetric methods with the moisture index measurements by a MOIST 200B of hf sensor GmbH (Leipzig, DE). The results show that the tested machine can give neither the quantity of adsorbed water vapour nor the quantity and penetration depth of capillary water in homogeneous and non-weathered samples under perfectly known and controlled conditions.

Introduction

Water is involved in a multitude of alteration processes (due to crystallization-dissolution cycles of salt, to hydric and hygric dilation-contraction of materials, to biological colonization, to freeze thaw cycles) and it is undoubtedly the dominant factor of degradation of mineral materials used on historic buildings. To restore and conserve these buildings, the potential sources, the penetration paths, the spatial distribution (2D on the exposed surface and 3D in depth) of water and the importance of its accumulation within the masonry need to be known and monitored. Petrophysical measurements allow to determine precisely the quantity of water contained in the pore space of mineral building materials (MBM), but to use these laboratory methods samples have to be taken. But, in the field of built heritage such destructive methods must as much as possible be avoided. That is why non-destructive testing methods to determine the water content of the MBM in situ would be highly welcome.

According to published articles (Göller 1999, 2000, 2001, 2007), the MOIST 200B of hf sensor GmbH seemed to be the ideal device for this purpose. That is why we decided to purchase one of these devices. Before using it in situ we tried to calibrate it in the laboratory on samples for which we did know the content and spatial distribution of water.

The tested device: MOIST 200B of hf sensor GmbH in Leipzig

According to the operation manual (hf sensor, non mentioned date), the MOIST 200B is a handheld microwave moisture meter designed for non-destructive moisture measurements in various building materials. It consists of a microcontroller based handheld and two sensing heads (SH) for moisture measurements in the volume (MOIST P and MOIST D) and in the surface area (MOIST R and MOIST R2) of the material under test.

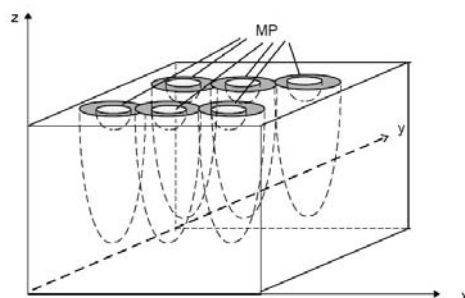


Fig.1 Surface and volume measurements. MP= measured points. According to Göller, 2001

This device is based on the dielectric moisture measurement method and it measures the difference between the permittivity of water and the permittivity of the solids. It measures the part of the microwave which is reflected from the material dependent on its moisture content. It works at a frequency range between 2 and 10 GHz where the corresponding wavelengths is supposed to allow a penetration depth in the decimeter range with antennas (MOIST D and P) and in a few centimeters depth with stray-field-sensors (MOIST R and R2) (Göller 1999, 2000, 2001, 2007; hf sensor not dated). Cf. fig.1.

We worked with the four following heads: MOIST R, supposed penetration depth (PD) of up to 3 cm, MOIST R2, supposed PD of up to 7 cm, MOIST D, supposed PD of up to 11 cm and MOIST P, supposed PD of up to 30 cm. The temperature range is from 0 to 55°C.

As the acquisition time for each measurement is about 5 sec., and as the SH can easily and quickly be changed, this device allows to record the moisture content of a material at different depths.

For specific materials, incl. sandstones, the SH are calibrated by hf sensor so that for these materials the device can be used on calibrated selection, supposed to give the dry basis moisture content (Mc):

$$Mc (\%) = \frac{W_w - W_d}{W_d} \times 100 \quad (1)$$

W_w (g) = weight of the wet sample; W_d (g) = weight of the dry sample.

For the measurements on materials whose calibration curves are not known, and for relative measurements, the position "Moisture Index" (MI) can be used. The MI is a dimensionless number between 0 and 4000 that is suppose to increase with the water content.

For more information concerning the operating principle of the device, see the articles cited above.

Materials and sample dimensions

As we want to use a water content measurement method on the cathedrals of Basel, Berne, Fribourg and Lausanne (Switzerland), we used fresh samples of sandstones that can be found on these monuments, respectively Buntsandstein sandstone Maintal and Wiesental and molasses-sandstones Gurten, Villarlod and Mercerie. On the 5 sandstones we determined their total porosity (on cubes 4x4x4cm), capillary water absorption kinetics and water adsorption isotherms (both on cubes 4x4x4cm and 15x15x15cm). Measurements of the moisture content with the MOIST 200B were made during capillary water absorption or water vapor adsorption on the 15 cm edge cubes. According to the hf sensor operation manual these dimensions allow to measure at a distance far enough from the lateral bounds (minimum distance from the lateral bounds of the object is given by half the diameter of the SH, i.e. 2.8 cm for the MOIST R, R2 and D SH) and with a thickness material greater than the minimum accepted (the minimum thickness of the material is respectively ± 3 , ± 7 , ± 11 cm for the MOIST R, R2 and D SH). As the limit conditions of the MOIST P SH were not respected (minimum distance from the lateral bounds of 4 cm and minimum thickness of ± 30 cm) we expected very bad results with this SH, but bigger samples are just too heavy to be convenient for the simultaneously executed petrophysical measurements (15 cm edge cubes of sandstone weigh between 7 and 8 kg!).

The calibration principle and the experimental procedure

Porous MBM can contain vapor and/or liquid water depending to the history and the environmental conditions of the building. To decide if an intervention is necessary, we need to be able to evaluate if the MBM contains vapor and/or liquid water and the amount of these waters. Petrophysical laboratory experiments allow to fill the porous network of the MBM with vapor and/or liquid water and measuring the corresponding quantities of water. The capillary water absorption experiment even allows to know where the liquid water is within the tested samples (Commission 25-PEM, 1980; Rousset, 2001). Firstly we measured the total connected porosity, P_t (2), of the sandstones by means of water uptake under vacuum to exactly know the maximum volume that could theoretically contain water. Further the bulk density ρ of the sample can also be calculated from this experiment ($\rho = W_w/V_b$ where V_b is the bulk volume). Then the capillary water absorptions were measured according to Commission 25-PEM (1980), which give the linear and specific capillary water absorption kinetics and the maximum part of P_t that can be filled with capillary water, i.e. liquid water, under atmospheric conditions. Finally the water adsorption isotherms were determined according to the procedure described by Rousset (2001) to know the equilibrium quantity of water vapor that can be adsorbed in the porous network at relative humidities (RH) of 33, 55, 75, 86, 93 and 97% and 20°C.

For both water uptake by capillary absorption or vapor adsorption, if the total porosity of the studied sample is known, it is easy to calculate either Mc (1), or the water saturation of the porosity, S (3).

$$P_t (\%) = \frac{V_v}{V_b} \times 100 \quad (2)$$

V_v (cm³) = total connected void volume of the sample; V_b (cm³) = bulk volume of the sample

$$S (\%) = \frac{V_w}{V_v} \times 100 \quad (3)$$

V_w (cm³) = void volume effectively occupied by water (whatever its form is)

And if Mc of a sample is measured during a capillary absorption or a vapor adsorption experiment, regardless of the measuring device used, S can be calculated from equation 5 if ρ and P_t are known:

$$S (\%) = \frac{Mc \times \rho}{P_t} \times 100 \quad (5)$$

Hence we measured Mc with the MOIST 200B on the surface of the 15 cm edge cubes during the petrophysical experiments of capillary water absorption and water vapor adsorption i.e. for several water saturation states of the samples and we compared the MOIST values to the petrophysical values. The MOIST measurements were performed under constant conditions: we measured at the center of the same smooth surface for each sample; all the samples laid on the same plastic empty stand; the surrounding temperature was $23 \pm 2^\circ\text{C}$ and the surface temperature of the samples was $22 \pm 2^\circ\text{C}$.

Results

At first, we have to discuss collateral first results:

- as the limit conditions for the MOIST P SH were not respected (cf. § Materials and sample dimensions) the results presented here after only concern the MOIST R, R2 and D SH;
- for the first measurements, we worked with the device position calibrated for sandstones. But we obtained Mc of 7% which correspond to S of more than 100% for the studied sandstones, i.e. non-viable values. So we quickly preferred to work with the MI;
- at the beginning of our experiments we also remarked that the location where we put the samples on the lab bench during the measurements had a great influence on the values given by the four SH whatever was the minimum thickness of the material indicated by the construction company, probably because of metallic parts within the furniture. Finally we placed the samples on an empty plastic stand of about 23 cm high that according to tests interfered little enough on the measuring values.

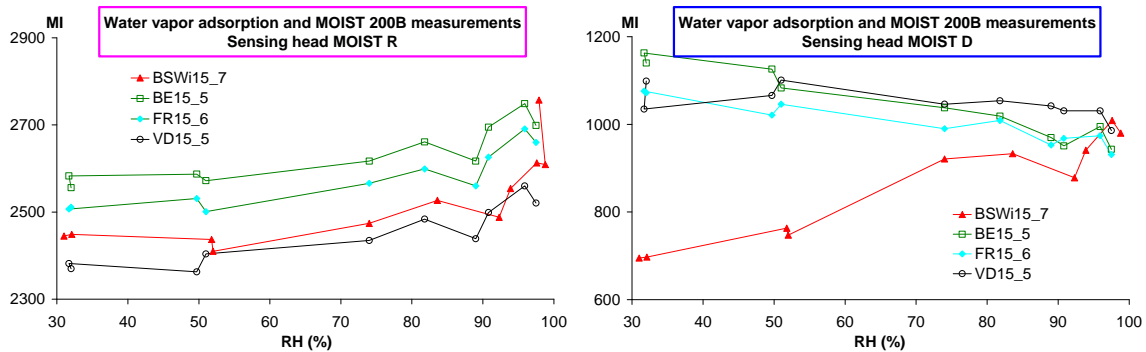


Fig.2 Variation of the MI measured on samples in equilibrium with various RH. On the left: results we obtained with the SH MOIST R on a Wiesental sandstone sample (BSWi15_7), a Gurten molasses-sandstone sample (BE15_5), a Villarlod molasses sandstone sample (FR15_6) and a Mercerie molasses sandstone sample (VD15_5). On the right: idem with the SH MOIST D.

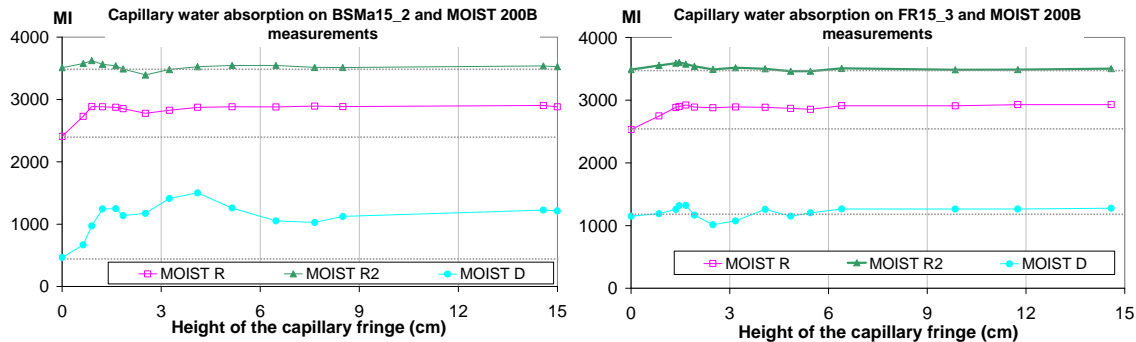


Fig.3 Variation of the MI measured by the penetration depth - or height - of the capillary fringe on a Maintal sandstone sample (BSMa15_2, on the left) and a Villarlod molasses sandstone sample (FR15_3, on the right): results from SH MOIST R, R2 and D

The more interesting results are:

- the results obtained with the MOIST 200B on dry samples depend on the mineralogical nature and the porous structure of samples on which the measurements are made;
- all the tested SH of the MOIST 200B are sensitive to adsorbed water and possibly as well to water vapor located in the pore volume: measuring the MI on samples that have reached equilibrium with respect to increasing RH, the values are also increasing and lay above those obtained on dry samples. However, an inexplicable trend was found for the SH MOIST D: for the studied molasses-sandstones (Gurten, Mercerie, Villarlod), the values decrease (and are therefore lower than those of the dry samples) when the RH increases, but the results are "normal" for the studied Buntsandstein sandstones (Maintal, Wiesental) (fig.2);
- during capillary water absorption, the values measured are at first much higher than the values measured on the dried samples: as long as the capillary fringe lies not deeper than 1 cm, the MI seems to increase quite systemically with the water penetration depth and therefore with the amount of water present in the sample. But as soon as the capillary fringe goes past 1 cm depth, the MI shows strange fluctuations, with no apparent correlation to neither the amount of water in the porous medium, nor the penetration depth of the capillary fringe (fig.3). For some samples, values obtained for deeper penetrations are even lower than those for dry state (fig. 3). Our related questions have remained without satisfactory response from hf sensor.

Conclusions

These results show that the MOIST 200B device has too big flaws to be used in the field of the cultural heritage conservation:

- it is useless on any masonry which may contain metal or on which metal elements could be set (strengthening structures, pipes, ...);
- as the influence of mineralogical and porous structures heterogeneity on its results is sometimes bigger than the influence of the water in the porous network, the results can never show if the analyzed MBM is dry, damp or wet. Therefore it can neither be used to obtain an absolute water content, nor to follow the evolution of the water content at a point with time, nor to compare the water content of several points, nor to map the water content distribution;
- for one or more reason(s) that we do not know, the MI oscillations observed when the capillary fringe is moving towards the depth are in no correlation to the actual distribution of the water in depth.

Acknowledgements

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