12th International Congress on the Deterioration and Conservation of Stone
Columbia University, New York, 2012

INNOVATED WATER UPTAKE MEASUREMENTS ON HISTORIC STONE SURFACES

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Abstract

An innovative method has been developed and tested at ITAM for measuring water absorption of porous materials under low pressure. It makes possible continuous or manually controlled electronic measurements of water infusion into the surface. This measurement procedure reduces the number of operators, and is more precise, more effective and faster. Two prototypes are available: one for continuous laboratory measurements and a portable prototype for *in situ* applications. The device has an output connector for linking it to a computer and reading the stored data. The portable device has been tested in laboratory conditions and also *in situ* for its basic performance on various types of stone and plaster surfaces, including treated and untreated historic materials. The acquired data are evaluated using software specially written for this purpose in MatLab, and the results are compared with standard capillary water uptake measurements on prismatic columns. Working with the innovative tubes, measurements can be made on complex stone or plaster surfaces, e.g. sculptures in a dense network. This feature is especially appreciated by restorers making interventions on materials that have been treated previously.

Keywords: water uptake measurements, microtube

1. Introduction

In situ testing of surface quality and material sorption of liquids represents one of very basic and indispensable techniques in the conservation practice. For on-site measurements, the so called Karsten tube has been used in recent decades. The application of the Karsten tube in situ brings about some difficulties, which can be summarized in the following way: i) problems with fixing a heavy glass tube on vertical surfaces, ii) problems with sealing the contact ring area, iii) a need for two operators – one who follows the water movement in the measurement tube together with stop-watch and another who records readings, iv) soiling of surface with the sealing putty.

Therefore, a pilot prototype of an innovative device has been developed in ITAM CET. It aims at a new design of the system based on the possibility of electronic continuous measurement of water infusion into the surface, which enables long term measurements and recording of the water sorption from the very beginning. The measurement reduces the number of operators, it is more precise, effective and faster (Drdácký et al. 2011).

2. State-of-the-Art

The above-mentioned Karsten tube was developed by Professor Karsten some forty years ago for in situ testing of façades in order to get information about their resistance to pouring rain. It has since become a standard device also to investigate natural stone surface characteristics relative to water absorption. It is used for estimation of surface characteristics related to consolidation or water-repellent treatment, as well as for post-treatment assessment of the efficacy of the intervention. The watering contact area is quite large, which may cause problems for measurements on a non-homogeneous pore system when cracks, damaged regions, water saturation or conspicuous structural heterogeneities are present. It has been shown that the method can give in many cases inaccurate or useless results (Pleyers & Sasse 1999).

Capillary properties of porous materials can be measured in situ by means of modified tools or methods (Drdácký et al. 2009, Zíma 2011). One method is represented by the so-called Mirowski tube, which is formed as a scaled glass pipe of 10 cm^3 in volume, which has proved to be suitable for in situ measurements. The outlet of this tube is covered with a porous plug (sponge), which mediates the transport of water into the measured surface. The penetration area is smaller than in the case of classical Karsten or RILEM tube.

Another substantial change was introduced by Martin Lehmann (2004) in his diploma work supervised by Prof. Heinz Leitner and Prof. Christoph Herm, where he suggested and tested a scaled glass capillary tube provided with an outlet of 9 mm in diameter filled with porous cellulose (paper) cigarette filter as the contact material. This innovation was initiated by restorers, who wanted to eliminate the soiling of fresco surfaces with the residues of the sealing putty or glue for fixing the tubes. The method has been further developed by Johannes Mädebach (2008) in his diploma work supervised by Dipl.-Rest. Thomas Schmidt and Prof. Christoph Herm. He used a capillary tube of volume of 120 μl and scaling of 1 μl, the contact outlet area being 50 mm^2. The outlet head was connected to the glass tube by means of a flexible hose, which enables measurement on any inclined surfaces, or even on the ceiling. However, the method still requires two operators.

Within the European STONECORE project, work it has been decided to approach all deficiencies mentioned in the introductory paragraph. The development has been carried out along two parallel modifications – a laboratory device and a device for in situ measurements (Drdácký et al. 2009). The differences are explained below.

3. Semiautomatic microtube system

In tandem with the hardware described in this chapter, basic measurement and evaluation software has been written. This part is still open to improvements taking into account various theoretical models and approaches to the interpretation of measured sorption data.

For continuous laboratory measurements, the classical Karsten scaled glass tube was replaced by a calibrated tube (water container) into which a float has been inserted. The float carries a core, which moves inside a fixed coil of electrical inductive sensor and the movement of the float corresponding to the water level movement is thus transferred to electrical output, which is recorded and can be further elaborated. The main elements of the laboratory device are shown in Figure 1. During the measurement, the tube is repeatedly filled with a given amount of water and the movement of the water level in the tube is recorded. The outlet is connected to the tube by means of a flexible hose and provided with a paper cigarette filter, which functions as a sealing interface between the outlet and the measured surface.

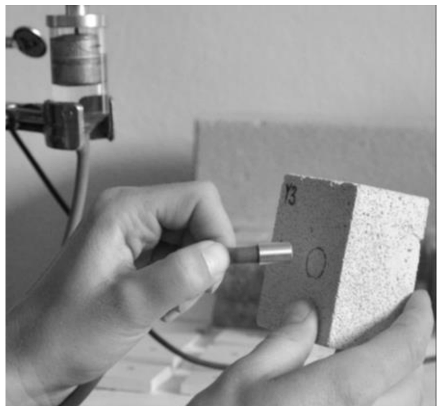

Figure 1. Water container with a float (left upper corner) connected with a flexible hose to the outlet with a paper cigarette filter through which the water is transported into the measured surface.

The approach to the portable device is driven by its great versatility, robustness and simplicity, which result in a low production cost. The first prototype is aimed at testing basic functions and is expected to be substantially modified, as development is continuing with the support of a national project within the NAKI Programme of the Ministry of Culture of the Czech Republic.

The first proposed portable devices are not fully automatic. The prototype consists of a box containing a microprocessor, which measures time and records the amount of a liquid which has penetrated into the investigated surface. The power on/off switch is inserted into the bottom of the device and protected against unintentional operation. The advanced prototype has a pistol type ergonomic holder of the micro tube, see Fig. 2.

During the measurement (after activating the power), individual series of measured data are started and terminated with the start/end I/O switch. Repeated switching starts another series of measurement. The switch (red button on the box or micro-switch on the pistol) is manually operated and pushed at the moments when the water meniscus in a capillary tube or in any other tube reaches the scale marks. So during the operation the coordinates of time and a scaled increment of the volume of penetrated water are recorded. The device has an output connector for linking to a computer and reading the stored data.

The water uptake velocity is followed on the scaled micro-tube kept in a holder, which is fixed to the pistol with a magnet, see Fig. 2. The holder enables fixing of other tubes, too, for example the Mirowski tube or even a Karsten when rotated into a vertical position and the holding fixtures are replaced by those matching the applied tube.

However, the horizontal capillary tube can be used for measurements on inclined surfaces (e.g. vaults) or ceilings.

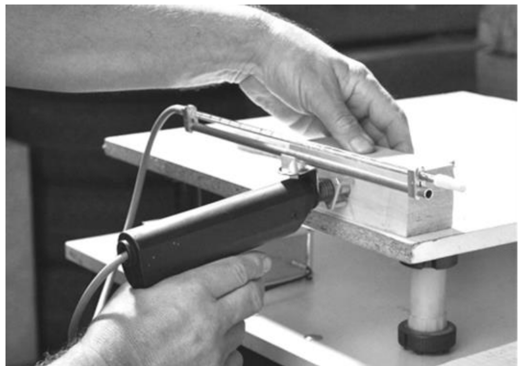

Figure 2. Pistol-like device consists of a scaled capillary tube in a tube holder adjustable in horizontal or vertical position (swivel connected), a connecting plastic hose ending with an outlet hinged head with a three point support, a switch for manual recording data, and a connection cable to data storage unit.

The pistol trigger is modified in the form of a micro-switch, which controls recording of the instantaneous real time value into a processor memory in the relevant set of the open group of measurement data. It is pushed when the water meniscus in the capillary tube crosses the scale line, corresponding in our case to the value of 0.01 ml. Of course, other scale lines can be used too, but then the evaluation software must be reset for the corresponding volume of water. The trigger is connected to the electronic unit through a cable with a connector.

It is possible to record 40 measuring groups (i.e. measurements at 40 places). Then the records should be skipped into a computer, the memory erased and the device is ready for another series of measurements.

4. Evaluation of data

The acquired data are evaluated using software specially written for this purpose in MatLab. In the pilot phase, no specific elaboration (e.g. regression) was carried out. However, we expect to enlarge the software capabilities and output forms according to discussion within the professionals. Figure 3 shows types of stone deterioration and Figure 4 presents the relevant typical results of water uptake.

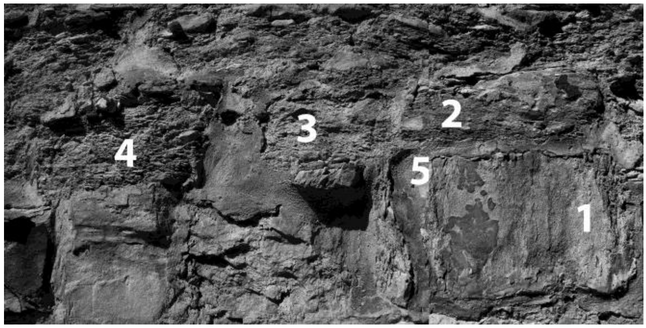

Figure 3. Measured points on a deteriorated stone wall (marly limestone - "opuka").

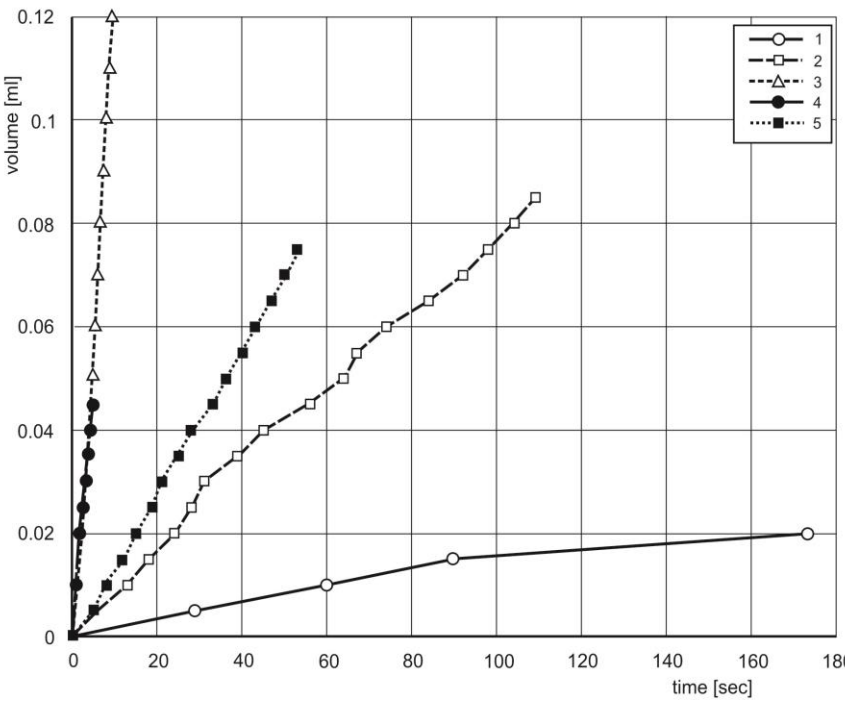

Figure 4. Evaluated data from in situ measurements on differently deteriorated opuka stone – from a rather compact (1), through slightly degraded (2) to seriously deteriorated and cracked (3) and (4). Line (5) relates to a vertically cracked part of the relatively compact stone on which the (1) measurement was done.

5. Performance of the device

Even though the device is rather simple, its operation requires certain skills and a trained and careful worker. The performance has been tested by various approaches. First, a comparison of water uptake data acquired by micro-tube measurements with data of capillary water uptake and with the Karsten tube has been completed. Then an estimate of the method's error has been studied.

5.1 Comparison of water uptake measurements

The comparative measurements were carried out by means of the portable micro-tube on short columns made of various stone, namely on sandstone and limestone. The volume of water absorbed by individual stone specimens has been evaluated for the time of 1 minute and 5 minute measurements due to a low volumetric capacity of the micro tube system. The acquired data were compared to the capillary uptake measurement and the Karsten tube measurement. The correlation of the 1 minute micro-tube measurement with the capillary water uptake as well as with Karsten tube is fairly good, see Figure 5. During the longer time measurement by micro-tube water leakage around the filter paper influences the results in a negative way and the correlation is worse.

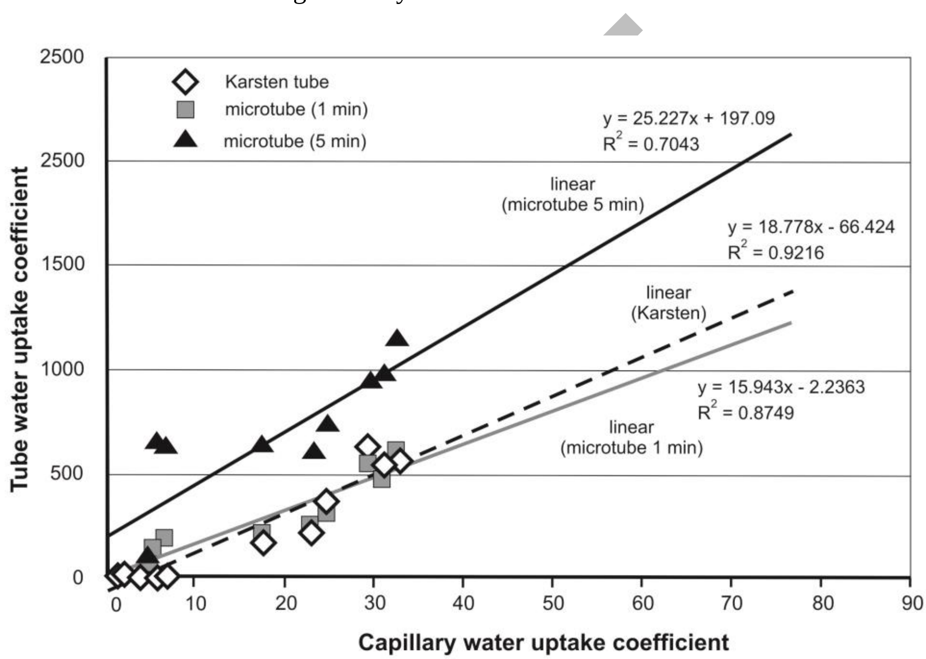

Figure 4. Comparison of the Karsten and micro-tube water uptake characteristics measured on various stone types, and their relation to the capillary water uptake coefficient classically measured on stone column specimens.

5.2 Estimate of the method's error

The work with the presented prototypes, namely with the portable device is operator sensitive. It is not easy without a short training and experience to keep the outlet firmly fixed to the sometimes irregular surface, follow the movement of the water meniscus and manually trigger the recording. In order to estimate the real error the following experiments were carried out.

Testing specimens were produced of highly homogeneous isotropic materials from the porosity point of view. Ceramic tiles, lightweight concrete and Hořice sandstone were used. Then their porosity was measured as well as their capillary water uptake by means of traditional approaches.

The water uptake has been measured on the specimens in one identical point ten to fifteen times, naturally, with breaks necessary drying the tested area and the adjacent volume. The statistics are given in Table 1 and typical measured characteristics are shown in Figure 5 and Figure 6. The strongly deviated data are always caused by problems with the tight contact between the cigarette filter and the measured surface. They have not been included in the evaluation. From the Figure 5 it is also seen that the first two measured points after the start are less accurate and it is recommended to skip them from the evaluation and assess the rate of soaking from the rest of the measured points. In this paper there are considered, which increases the determined error.

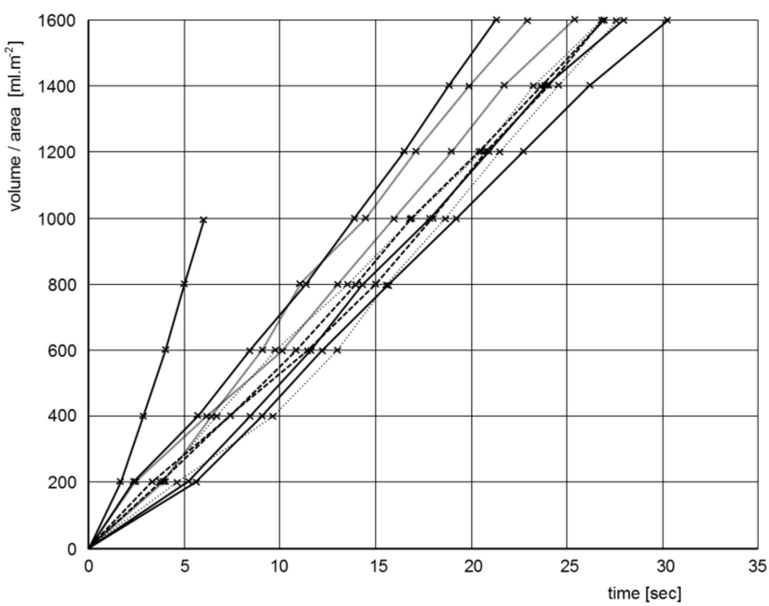

Figure 5. Series of measurements in one identical point on a ceramic tile specimen K6.

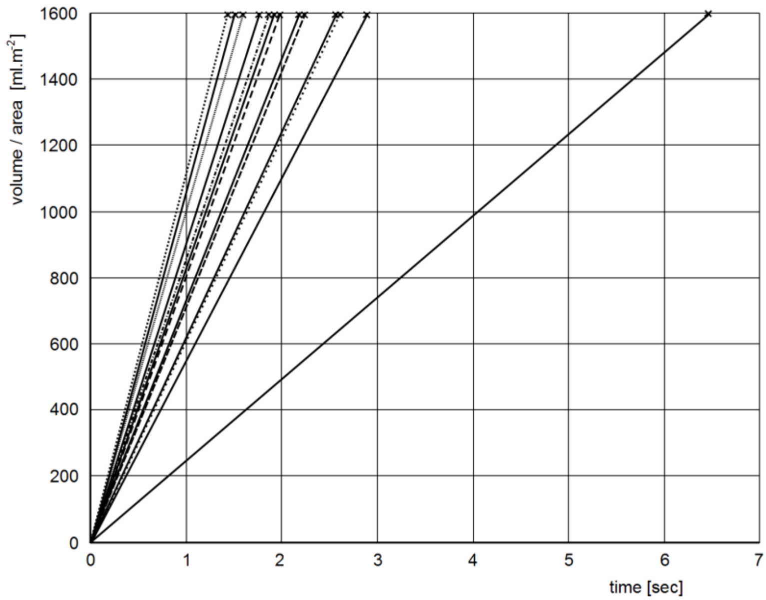

Figure 6. Series of measurements in one identical point on a Hořice sandstone specimen.

Table 1. Testing of the method sensitivity to the operator skills

Specimen	Outlet diameter	Total counts	Evaluated counts	Average time	Standard deviation	Variation coefficient	Water uptake
	mm			s	s	%	ml/m^2/s
Ceramic tile K3	8	10	9	28,68	4,29	14,97	55,49
Ceramic tile K6	8	10	9	26,18	2,75	10,49	60,79
Average ceramic tile				***27,43***	***3,52***	***12,73***	***58,14***
Sandstone Hořice S5II	8	13	11	7,00	0,94	13,40	227,25
Sandstone Hořice S5II	8	13	10	1,57	0,22	14,11	1011,15
Sandstone Hořice capillary rise					*3,07*	*12,48*	*24,88**

*in [kg/(m^2.hour^{0,5})]

The variation coefficients can be compared to those measured on the Hořice sandstone at capillary rise, and the values acquired by D. Vandervoorde et al. (2011) during their testing of the contact sponge. They measured variation for capillary rise between 11,5% and 14% for various stones, and from 23% to 62% for the Karsten tube and from 30,6% to 71,4% for the Mirowski tube.

The micro tube measurement avoids any sealing, however, the cigarette paper filter used instead of sealing may allow for some leaking, especially if it is too long and then may be destroyed at the moment of a firm attachment. In such a case it is recommended to stop the measurement, insert a new filter and to start again. The measurement is so fast and the affected area so small that such an approach does not create any problem.

6. Conclusion

The micro-tube or the "float tube" proved to be a useful tool for measurement of water uptake characteristics on porous materials. The innovative micro-tube method enables easy and fast operation, easy storage of data and their further elaboration, measurements on arbitrarily inclined or highly curved surfaces, considerate application without soiling the investigated surface with putty, and measurements in a dense array of points.

This simple technique, which takes advantage of a combination with modern digital technologies and numerical methods provides the restorer-conservator with an affordable instrument for in situ assessment of an important material characteristic, which is difficult to measure in situ by other means.

For example, the so called Karsten tube has many limitations and deficiencies, which makes the method applicable to a limited extent only. The recently introduced sponge method has also disadvantages consisting in a rather large area of the necessary contact to the measured service, and the firm contact over the whole area, which is difficult to assure. Further, the absorbed amount of water must be measured using a balance, which is also in situ complicated. In practice, the number of measurable places is fewer than with the micro-tube. Only the overall absorbed volume is registered without a possibility to follow the course of water uptake in time.

However, the available prototypes are still operator sensitive and a reliable application requires to carry out several measurements on the surface, and calculate the average.

The correlation with the standard capillary water uptake coefficient is very good and comparable to the Karsten tube measurements. Nevertheless, it is possible to attain a much better reliability at the measurement than with the Karsten or Mirowski tube.

7. Acknowledgements

The authors acknowledge a kind support from the Ministry of Culture of the Czech Republic within the NAKI Programme projects No. DF11P01OVV001 "Diagnostics of damaging and life span of cultural heritage objects", and from the institutional support RVO 68378297. The authors further thank to Ms. Delphine Vandevoorde for fruitful discussions on her practical experience with the developed portable device and the sponge method.

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