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Measurement of Water Uptake of Historic Surfaces - State of the Art Review

Pavel Zíma

Abstract: In situ testing of material water uptake represents one of very basic and indispensable techniques in the conservation practice aiming different purposes. Water uptake of porous building materials used on historical constructions significantly correlated to some other material characteristics. Capillary properties of porous materials can be measured by means of Karsten tube and modified tools or methods. A pilot prototype of one of them has been developed and tested in ITAM AS CR for measuring water absorption under low pressure. The device has output connector for linking to a computer and reading the stored data. The device was tested in laboratory as well as in situ for a basic performance. The acquired data were evaluated using software specially written for this purpose in MatLab.

Keywords: Water uptake, Karsten tube, Mirowski tube

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 the measurement the so called Karsten tube has been used for several recent decades.

The application of the method in situ brings about some difficulties which can be summarized in the following way:

- problems with fixing a heavy glass tube on vertical surfaces,
- problems with sealing the contact ring area,
- a need for two operators – one who follows the water movement in the measurement tube together with stop-watch and another who records readings,
- soiling of surface with the sealing putty.

Therefore, a pilot prototype of an innovated device has been developed. It aims at a new design of the system based on a 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.

2. State of the Art review

The above mentioned Karsten tube was developed by Professor Karsten some forty years ago for in-situ testing of facades in order to get information about their resistance against pouring rain. Later it has become a standard device also to investigate natural stone surfaces characteristics relative to water absorption. It is used for estimation of needs for surface preparation for treatment with consolidation or water repellent materials as well as for assessment of the intervention efficiency after the treatment.

The classical Karsten tube device is composed of a tube formed in a way where a defined surface circular area is wetted and penetrated by water or an impregnation agent. The ascending pipe with a calibrated printed division [ml] is used to measure the time dependent absorption behaviour per surface area.

The tube and its use was standardized by several institutions, namely by RILEM, ASTM, and several national standard authorities.

2.1. RILEM standardized application (according to compilation by Frances Gale 1987)

RILEM Test Method 11.4 provides a simple means for measuring the rate at which water moves through porous materials such as masonry and gives data on the volume of water absorbed by a material within a specified time period.

The equipment necessary for measuring water absorption under low pressure is simple. The test can be performed at the site or in the laboratory with a test apparatus available in two forms. One is designed for application to vertical surfaces and measures horizontal transport of water, or, its resistance to wind-driven rain penetration[1]. A second form is designed for application to horizontal surfaces and measures vertical transport.

Fig. 1 illustrates the pipe-like apparatus designed for measurement of vertical surfaces (right glass tube). Its flat, circular brim (at the bottom end of the pipe) is affixed to the masonry surface by interposing a piece of putty. The open, upper end of the pipe has an area of 5.7 cm^2. The vertical tube is graduated from 0 to 4 cm^3. The total height of the column of water applied to the surface, measured from the centre point of the flat, circular brim to the topmost gradation, is 9.8 cm. This corresponds to a pressure of 961.38 Pa, or, a dynamic wind pressure of 142.6 kilometres per hour. The apparatus designed for application to horizontal surfaces, is similar to the one for vertical surfaces as described above and can be seen in Fig.1 on the left side.

Fig. 1. Set of glass Karsten tubes for measurements on vertical and horizontal surfaces with a bottle of water for filling the tubes and stop-watch for time measurement.

[1] *It should be noted that a standard method for measuring water penetration and leakage through masonry is also described in ASTM E 514. The ASTM test method is intended to evaluate wall design and workmanship as well as the degree of weathering and the performance of water repellent treatment. It is therefore necessary to conduct the procedure on a test wall built with a minimum height or length of four feet. The wall is exposed to water (3.4 gallons per square feet per hour) in a test chamber for four hours.*

The testing apparatus is affixed by interposing a tape of putty between the flat, circular brim of the pipe and the surface of the masonry material. To ensure adhesion, manual pressure is exerted on the cylinder. Water is then added through the upper, open end of the pipe until the column reaches the 0 gradation mark. The quantity of water absorbed by the material during a specified period of time is read directly from the graduated tube. The periods of time appropriate for the test depend on the porosity of the material on which the measurement is being made; generally 5, 10, 15, 20, 30 and 60 minute intervals provide the most useful data. In many cases, it may be important to measure water absorption through the mortar joint as well as through the surface of the brick (or natural stone) substrate.

Results of the test measurements are presented in the form of a water absorption graph with the volume of water absorbed in cubic centimetres reported as a function of time in minutes. The surface tested must be mentioned in the report.

Water has long been associated with deterioration processes affecting masonry materials. Its presence within the interior pore structure of masonry can result in physical destruction if the material undergoes wet/dry or freeze/thaw cycling. Thus, results obtained using Test Method 11.4 can be used to predict potential vulnerability of untreated, un-weathered masonry materials to water-related deterioration.

Test Method 11.4 also provides useful information when carried out on weathered masonry surfaces. Water permeability of a material is affected when its surface is obscured by the presence of atmospheric soiling or biological growth, or, when there are hygroscopic salts within the interior. The formation of a weathering crust due to mineralogical changes occurring on the exposed (weathered) surface may substantially affect water permeability measurements. By comparing data obtained on masonry that has been exposed to the elements with measurements made on un-weathered samples, it is possible to measure the degree of weathering that has occurred.

Finally, RILEM Test Method 11.4 can be used to evaluate the performance of a water repellent treatment. An effective treatment should substantially reduce surface permeability of the masonry material to water. By so doing, the treatment will reduce the material's vulnerability to water-related deterioration. A comparison of test results obtained on treated masonry samples with those obtained on untreated samples provides information about the degree of protection that can be provided by the water repellent treatment.

Although the testing device looks rather simple the geometrical boundary conditions are complex and in many cases the reason for inaccurate or useless results [7]. This is due to the growing penetration volume around the contacted circular area of the material surface. To get more accurate results a penetrated cylinder volume is necessary. The practical case may be described approximately by adding the volume of a rotating quadrant around the ideal cylinder to the cylinder volume, which has been solved by [13]. They developed special software for the relevant calculations supposing ideal geometric conditions on a homogeneous stone volume [9]. However, problems arise for a non-homogeneous pore system when cracks, damaged regions, water saturation or remarkable structural heterogeneities are present. It is expected that about 50% of field measurements cannot be evaluated correctly using such an ideal mathematical model. [8] introduced and patented another methodology.

2.2. Modified Karsten tubes

Capillary properties of porous materials can be measured by means of modified tools or methods. One of them is represented by so called Mirowski tube which is formed as a scaled glass pipe of 10 cm^3 in volume which 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 [4] in his diploma work[2] where he suggested and tested scaled glass capillary tube provided with an outlet of 9 mm in diameter filled with porous cellulose (paper) cigarette filter as the contact material. The reason for this innovation was initiated by the restorers who wanted to eliminate soiling of fresco surface with the rest of sealing putty or glue for fixing the tubes. The method has been further developed by Johannes Mädebach (2008) in his diploma work[3]. He used capillary tube of volume of 120 µl and scaling of 1 µl, the contact outlet area has dimension of 50 mm^2. The outlet head was connected to the glass tube by means of a flexible hose which enables measurement on arbitrary inclined surfaces, even on the ceiling.

2.3. Automatic measurement modifications (according to[6])

Other methods exist for the determination of surface porosity. One which has been used over many years as a successful guide to the weathering durability of architectural products and cast stone is the so called initial surface absorption test (ISAT), which is described in BS 1881 Part 5 [2]. This test, which has been the subject of rigorous evaluation by [5], has the advantages of relative simplicity and low apparatus cost, and of yielding results which correlate with field experience. However, the test procedure relatively lacks accuracy when rates of absorption are very high or very low and is labour intensive. Therefore, a method for continuous monitoring and improved resolution and accuracy has been developed.

The basic ISAT apparatus consists typically (for laboratory work) of a domed cap, preferably in clear plastics, which is clamped tightly onto the test surface. A rubber gasket ensures a watertight seal. Water is supplied from a reservoir at a head of 200 mm relative to the test surface via the inlet tube. The outlet tube is connected to a horizontally mounted capillary tube at the same height. At the start of a test, water is supplied from the reservoir to fill completely the cap and connected capillary tube. The connection to the water supply is then closed and any water subsequently absorbed by the sample is translated into travel of the meniscus along the capillary. The range of absorption rates which can be accommodated is influenced by the sizes of capillary bore and test area. The capillary tubes used in the present work were of 1 mm^2 and 6.2 mm^2 bore cross-sectional area. Two cap sizes were used of external diameter 40 mm area 1257 mm^2) and 85 mm (test area 5675 mm^2).

The meniscus in the tube is monitored continuously by a line-scan camera controlled by a BBC Master computer. The optical arrangement developed for monitoring the meniscus in the tube takes advantage of its illumination by a short fluorescent lamp and observation by the line-scan camera (LSC) focused on the capillary bore. The LSC is fitted with a standard Nikon 55 mm micro lens and a solid-state sensor which consists of a linear array of photodiode sensors onto which the image of the capillary bore is projected. The photodiode array contains 1024 photodiodes spaced 25 µm apart and the information on the array is obtained by scanning through its entire length to determine the amount of light falling on each diode in turn. This operation which takes 7 milliseconds is carried out by a dedicated microprocessor unit which in turn communicates with the BBC Master computer via a serial data link. Each scan of the array generates a voltage ‘video’ which is analogue in amplitude, according to the light intensity and digital in position being stepped from 1 to 1024. With the optical arrangement adopted, the camera monitors a length of approximately 100 mm of the capillary tube. This gives a resolution of approximately 0.1 mm, which corresponds to water volumes of

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[2] *Supervised by Prof. Heinz Leitner and Prof. Dr. Christoph Herm*
[3] *Supervised by Dipl.-Rest. Thomas Schmidt and Prof. Dr. Christoph Herm*

0.1 µl and 0.62 µl for the two tubes used. One sweep of the meniscus across the field of view accordingly corresponds to quantities of 100 µl and 620 µl.

Continuous operation of the apparatus requires that the tube be periodically refilled to ensure that the meniscus constantly remains in the camera's field of view. This is achieved under software control so that as the meniscus approaches the lower limit an electromechanical valve in the water feed to the cell is opened momentarily in order to restore the position of the meniscus to the upper limit. Results are then recorded repeatedly and automatically. As detailed in BS 1881 the test procedure involves the determination of the initial surface absorption rate in mL m^{-2} s^{-1} after intervals of 10 min, 30 min, 1 h and 2 h, from the start of the test. The LSC provides a continuous measurement of the absorption process and permits the expression of absorption rate at any desired interval.

Such a device is not suitable for in situ measurement even though the principle of optical reading might be applied and the mechanism of repeated filling is indispensable for any long term measurement system.

3. Description of the developed device

It has been decided to approach all deficiencies mentioned above, i.e.

- problems with fixing a heavy glass tube on vertical surfaces,
- problems with sealing the contact ring area,
- a need for two operators – one who follows the water movement in the measurement tube together with stop-watch and another who records readings,
- soiling of surface with the sealing putty, at east partly.

However, the development has been carried out along two parallel modifications – a laboratory device and a device for in situ measurements. The differences are explained below.

Next to 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.

Fig. 2. Tube of laboratory device with the float and measuring sensor

For continuous laboratory measurements the classical 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 coil of electrical inductive sensor and the movement of float is thus transferred to electrical output which is recorded and can be further elaborated. The main element of the laboratory device is shown in Fig. 2. 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.

3.1. Portable device

The approach to the portable device is driven by its maximum versatility, robustness and simplicity which yields a low production cost. The first prototype is aimed at testing basic functions and it is expected to be substantially modified on the way to a final result.

Therefore, the suggested device is not fully automatic. It consists of a box containing a microprocessor which measures time and records amount of a liquid penetrated into the investigated surface. Power on/off switch is inserted into the bottom of the device and protected against unwilling operation. Two magnetic holders may carry glass calibrated tubes including Karsten or Mirowski tubes, Fig. 3.

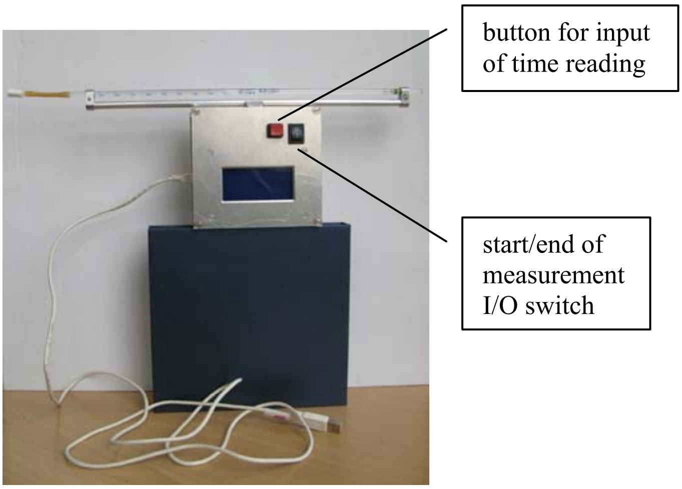

Fig. 3. Device

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 red button 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 display shows the sequential number of the measured series (# n) and the date in the format of MM/DD/YYYY and time in the format of HH:MM:SS. The device has output connector for linking to a computer and reading the stored data. The internal memory is pre-programmed for storage of 20 series of measurements.

4. Performance tests in situ

The device was tested in laboratory as well as in situ for a basic performance. The in situ measurement was carried out during inspection of sites selected for an application of CaLoSiL on a deteriorated opuka wall. The application is illustrated by Fig. 4.

Fig. 4. Recording water absorption into opuka wall using "electronic" stop-watch and capillary tube with flexible outlet arrangement and cigarette filter contact medium.

From the Fig. 4 it follows that the device can be operated by one person only. The use capillary tube with sponge-like contact enables fast measurements in various points even on surfaces where an attachment of the classical Karsten tube is problematic or impossible. No sealing was applied. The device can be used as a simple electronic stop-watch for measurements with classical Karsten tube, too.

5. Evaluation of the measured data

The acquired data were evaluated using software specially written for this purpose in MatLab. In the pilot phase no specific elaboration, (e.g. regression), was carried out. However, it is expected to enlarge the software capabilities and output forms according to discussion within the consortium. Fig. 5 shows the results including types of stone deterioration.

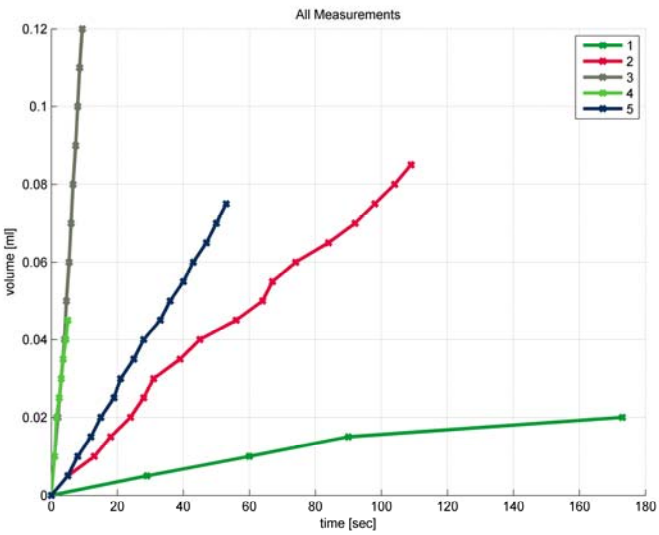

Fig. 5. Evaluated data from in situ measurements on differently deteriorated opuka stone – from a rather compact (1), through slightly degraded (2) to seriously deteriorated and cracked (3) and (4). Line (5) relates to a vertically cracked part of the relatively compact stone on which the (1) measurement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

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