Water-Absorption-Measurement instrument for masonry façades

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ABSTRACT: This paper introduces an in-situ device for measuring the water absorption coefficient of masonry façades. The „Water-Absorption-Measurement" instrument (WAM) allows non-destructive determination of the time-based function of water penetration. In a dense stack box a masonry façade area of 0.40 × 0.51 m is watered by nozzles. The gravimetric measuring system reaches a repeatable accuracy up to ± 8.3×10^{-4} kg / (m^2 × √s). Especially on fair-faced masonry, it is possible to measure the water penetration on an average area with bricks and mortar. This report contains detailed information about functionality of the developed measuring concept. Measuring results with laboratory- and a masonry façade are demonstrated. Customary instruments like the RILEM tube are compared to the developed measuring instrument.

1 GENERAL INSTRUCTIONS

Protection against rain water penetration is an important factor in building physics for the evaluation of historic masonry façades. If rain water hits the building materials of the masonry façade, it can infiltrate into the building structure by capillary power. Damages caused by moisture such as damage by frost can be the result of too much water penetration. The resistance to capillary water penetration is described with characteristic values of the basic material water absorption coefficient (A_w). The lower the water absorption coefficient, the higher the protection against capillary water penetration and associated moisture based damage. Limits for the A_w -value for masonry façade materials are defined in various standards (e.g. plaster standard EN 998-1, DIN 4108-3 for climate-related moisture protection or WTA Guideline 6-4 for planning inside insulation). Depending on rain load, position, orientation and design of the masonry façade, these values are ranged between 3.3×10^{-2} and 1.7×10^{-3} kg / (m² × √s). In a region of high rainfalls for example, a maximum value A_w of 8.3×10^{-3} kg / (m² × √s) is prescribed for exterior plaster. Furthermore, the A_w -value is required for hygrothermal simulations on façades. If the A_w -value of a masonry façade is known, the moisture behavior can be simulated by using numerical programs.

The A_w -value is determined in the laboratory by using a standardized test. The EN ISO 15148 describes the necessary procedure. It provides the basis for all further considerations. In the experiment, an air-dried sample is immersed a few millimeters in a water bath. At defined time intervals, the sample has to be removed from the water and weighted. The weight gain of the test specimen corresponds to the amount of water absorbed. The medium rise of weight gain referring to the surface of the immersed test specimen (1) and the root of the duration of the test (2), the water absorption coefficient of the sample construction material in kg / (m² × √s) is calculated therefrom, with:

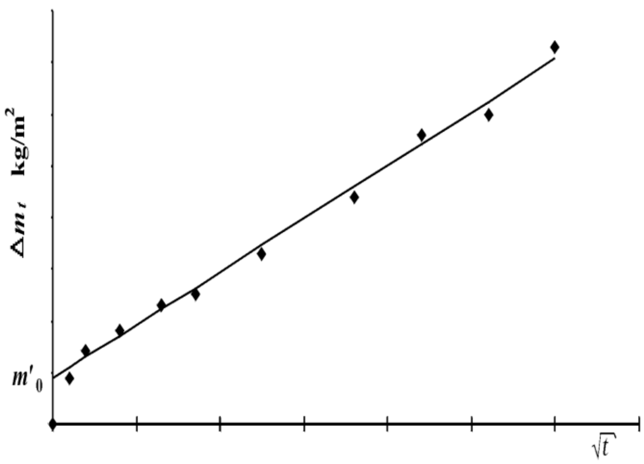

Figure 1. Graph of water absorption plotted to root of time (EN ISO 15148).

$$\Delta m_t = \frac{(m_t - m_i)}{A} \tag{1}$$

where m = weight of test specimens; A = surface of the immersed test specimen and

$$A_w = \frac{\Delta m'_{tf} - \Delta m'_0}{\sqrt{t_f}} \quad (2)$$

where $\Delta m'_{tf}$ = the value of Δm at medium rise by weight of test specimens to surface of the immersed test specimen of test specimens; t_f = testing time.

For a precise examination of historic masonry façades destructive taking of samples is necessary. In order to make a representative statement about an entire façade, several points should be investigated accordingly. This is not always possible in terms of historic masonry façades. Here it is necessary to use other non-destructive measurement techniques that can be used directly on masonry façades.

2 PREVIOUS NON-DESTRUCTIVE MEASURING DEVICE

There are already a number of methods available for determination the water absorption coefficient of masonry façades. The main methods for non-destructive testing are described in this section. In (Möller & Stelzmann 2013) the pros and cons of the following examination methods are presented.

2.1 *RILEM tube*

The RILEM tube (RILEM 1980) is a classical tool for consultants for determination of water absorption of façades. The RILEM tube is nearly 0.13 m tall and has an absorption surface area about 4.91×10^{-4} m². Using permanent elastic sealing putty the device made from glass or plastic is attached to a sample area. The unit is filled with water by a small tube with a printed measurement scale.

Figure 2. Vertical application of Rilem test method no. 11.4 RILEM tube is fixed on wall.

Thru reading the water level in the tube, the water consumption of material is concluded. Usually a measurement period is takes 15 minutes. The readings in ml/min are to be compared with limit values in the end. The RILEM tube is an easy manageable, inexpensive and fast device. Due to a smaller absorption surface area it is necessary to do many measurements. With a large scattering the water activity of the façade can be valued. Besides, the sealing putty is affecting the examination surface. Another disadvantage of this procedure is to achieve a permanent hydraulic water pressure, which pressurizes the test surface. Thereby micro cracks are rated too critically in practice.

2.2 *Testing panel for water permeability as per Prof. Franke*

A further development of the RILEM tube is the testing panel for water permeability as per Prof. Franke (Franke & Bentrup 1991). This device has been invented for testing a masonry hydrophobic treatment. The absorption surface area of the device is 0.25 m wide and 0.081 m high. Therefore the test panel for water permeability has a larger examination area as the RILEM tube. The measurement duration is typically 15 minutes. Attaching and measuring process have nearly the same functionality as the RILEM tube. In case of the water absorption testing panel after Franke the readings will be compared with prescribed limit values. Hydraulic water pressure also appears on the examination surface underneath the device.

Figure 3. Testing panel for water permeability as per Prof. Franke is used on a historical fair-faced masonry façade.

2.3 *ASTM C1601*

The international standard ASTM C1601 describes a field study to determination of water absorption of masonry façades. The sample is implemented in a testing box with an absorption surface area of about 1 m². The enclosed masonry façade surface gets artificially sprinkled with water. The loss of water corresponds to the amount resorbed water by the masonry façade. It is necessary to anchor the testing box on the masonry façade. The representative absorption surface area of 1 m² is being examined. The measurement duration is about 4 hours. Inside the device the air pressure is being artificially increased by a blower. Towards the reading of the amount of water absorbed by the façade, the water level is monitored in a container. The accuracy during a reading is ± 0.1 l. In contrast to the two methods, described before, the field study is working with significant lower pressure. The ASTM C1601 is a complex and time-consuming procedure. Furthermore it is a partially destructive testing method.

Figure 4. Measuring instrument determination of water absorption of masonry facades after ASTM C1601 (BDG-USA 2015).

3 DEVELOPED MEASURING METHOD

Since 2012 a new in-situ device called „Water-Absorption-Measurement" instrument, has been developed at the University of Applied Sciences in Leipzig. This new measuring method is able to determine the water absorption coefficient of masonry façades.

A schematic sketch of the principle is shown in figure 5. This new developed measurement method is based on the principle of ASTM C1601. Contrary to ASTM C1601 it has a smaller reference surface of 0.2 m². Furthermore a gravimetric principle of measurement is used in the „Water-Absorption-Measurement" instrument. For measuring process the „Water-Absorption-Measurement" instrument is fixed directly on the surface of the masonry façade with a special sealing compound. Additionally the instrument can be attached to the façade directly on the scaffold or on a hook.

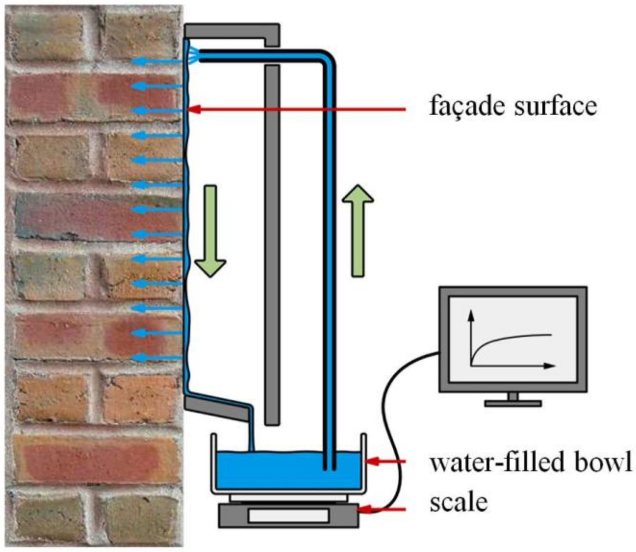

Figure 5. Schematic sketch of the principle of developed „Water-Absorption-Measurement" instrument.

The prototype of the „Water-Absorption-Measurement" instrument ist shown in figure 6. The result is a waterproofed area with the dimensions of 0.40 × 0.51 m. With the help of a pump the area of the façade can be artificially sprinkled. A closed water film is formed in the surrounded façade area. Depending on the quality of the masonry façade a part of the water gets absorbed. The rest flows back through a vent into the water container. A water circulation with just one way out over the surface of the façade is consisting. The weight of water container is measured permanently with a scale underneath. The loss of mass corresponds to the water absorbed by the masonry façade. The gravimetric measurement principle achieves a reproducible accuracy of ± 8.3×10^{-4} kg/(m²×√s). With the innovative procedure a representative area of 0.40 × 0.51 m is measured. Especially for fair-faced masonry façades this possibility of an integral measurement of the water absorption coefficient yields over more than one stone and joint layer. In the end of a measurement the „Water-Absorption-Measurement" instrument is removed without leaving a trace on the façade. One measurement duration is taking usually 3.600 sec, however this is not depending on the measurement principle. For instance a strongly sucking underground can already lead to a significant result after 1.200 sec.

During a subsequent evaluation the mass of the container before and after measurement as well as the continuously difference in weight of the water container were calculated up to a function of the water absorption. In consideration of the additional loss of water throughout the system, such as moistening within the measuring chamber, evaporation rate and water edge effects. Out of the function of the capillary water absorption is the water absorption coefficient analogue to an evaluation according to EN ISO 15148 determined. During different laboratory tests the new developed measuring method achieves a reproducible precision up to $\Delta A_w = 8.3 \times 10^{-4}$ kg / (m² × √s). In (Stelzmann et al. 2013, Möller & Stelzmann 2013) more studies describe the edge effects, the instrument calibration and measuring results.

Figure 6. Prototype of developed „Water-Absorption-Measurement" instrument at a historical fair-faced masonry façade.

4 LABORATORY EXPERIMENTS

The following section contains results of tests with in-situ-devices that are explained before. In a laboratory experiment the RILEM tube, the testing panel for water permeability as per Franke and the „Water-Absorption-Measurement" instrument were compared to the standard test EN ISO 15148. The Surrounding temperature was about 22 ± 3°C, relative air humidity ranges between 35 % -r.h. and 50 % -r.h. Calcareous sandstone and autoclaved aerated concrete material were used. For this test bricks without separations were utilized. The size of the test specimens is about 0.51 × 0.57 × 0.115 m. Both materials are artificial and homogeny, therefore ideal conditions for experiments in a laboratory are created. For fixing the devices an elastic sealing was used. Before the devices were added, the test specimens were dried in a furnace. The testing time of each individual measurement of the various devices was all in all 60 minutes. The A_w -values were determined in accordance to EN ISO 15148. It means in effect that the different size of the measuring area of the specific examination method is used for calculation.

Results of the laboratory experiment are shown in figure 7 and 8. The number of single measurements of each material was by RILEM tube more than 20, by other methods more than 5. Results by RILEM tube present a high variation of single values. Also the average values do not associate with standard test EN ISO 15148. The testing panel for water permeability as per Franke and the „Water-Absorption-Measurement" instrument have little scattering and nearly correspond to EN ISO 15148.

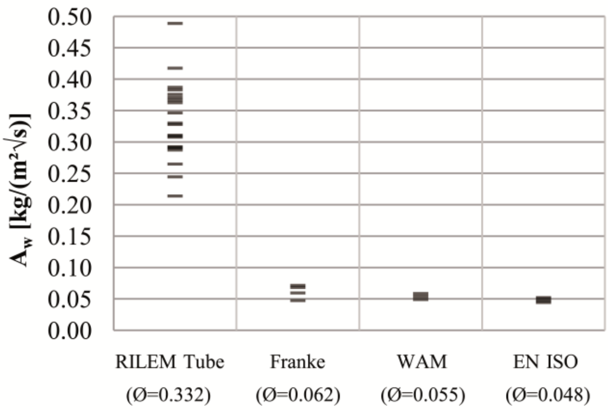

Figure 7. Measuring results of calcareous sandstone by laboratory experiment.

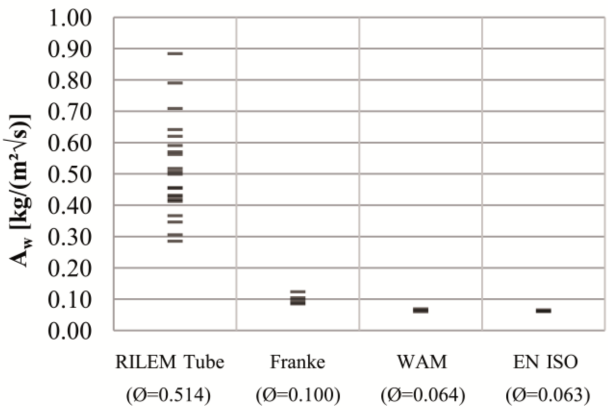

Figure 8. Measuring results of autoclaved aerated concrete by laboratory experiment.

5 FIELD EXPERIMENTS

In the next step the RILEM tube, the testing panel for water permeability as per Franke and the „Water-Absorption-Measurement" instrument were tested on a building façade. At these in-situ-tests it was not possible to take samples for testing in labratory. The results of all three in-situ-devices can be compared to each other. The tested façade is a historical fair-faced masonry in Leipzig, Germany (Figure 9). The house was renovated before the tests. The clinkers were cleaned and mortar joints were changed. For renovating the façade, first the old joints were removed completely about 2 cm deep inwards the façade-surface. Then a low hydrophobic effect was applied to the old clinker.

Figure 9. Tested historical fair-faced masonry façade in Leipzig, Germany.

Now the façade was flatly grouted with a mortar-sludge. Finally the clinkers were cleaned by rests of mortar. The main aim of these tests is to quantify the quality of wind-driven-rain-resistance. Therefore the main criterion is the averaged water absorption coefficient of the façade surface materials. The research object got a renovated historical façade as fair-faced masonry. To define the water absorption coefficient of the façade, it is necessary to measure clinker and mortar. Especially at the RILEM tube the measuring results are weighting by part of clinker and mortar. During the measurement no difficulties occurred. Figure 10 contains the results of the in-situ-tests. A typical graph of measuring data by the „Water-Absorption-Measurement" instrument is shown in Figure 11.

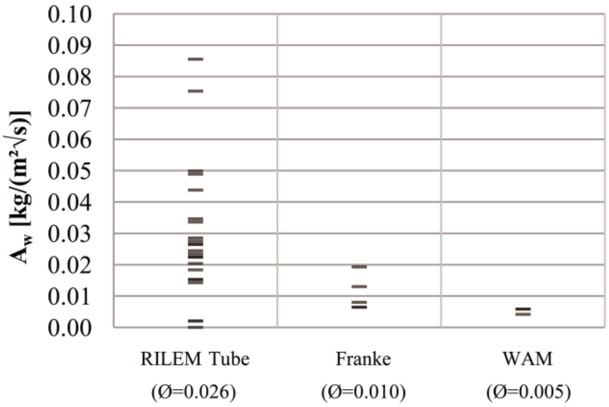

Figure 10. Measuring results of field experiments for determinate water absorption coefficient at historical masonry façade.

The measured values for the RILEM tube are excessive scattering. In contrast to results of the laboratory experiment the average value for the RILEM tube is substantial smaller. The scatter of the testing panel for water permeability as per Franke and the „Water-Absorption-Measurement" instrument are significantly smaller. The WAM instrument has, compared to the method as per Franke, a lower absolute value. Nevertheless the absolute A_w -value of the method as per Franke is twice as big as the absolute A_w -value of the WAM instrument. As a cause for these results the different sized measuring surfaces within the methods can be named. A relatively larger measuring size is the result of less influence of edge effects und a representative sample. A lower testing-pressure is the result of less influence of fine cracks and tear off by clinker and mortar. In addition, more examination results of masonry façades are shown in Stelzmann 2013, Möller & Stelzmann 2013).

As a Result, the RILEM tube is to be utilized for estimation of water absorption of masonry facades. Consequently, it is not possible to measure the water absorption coefficient with a needed accuracy thereby. The testing panel for water permeability as per Franke has a bigger absorption surface area. For specific application it is possible to assess the water absorption coefficient of masonry facades by the method as per Franke. In contrast to the RILEM tube and the testing panel for water permeability as per Franke, the „Water-Absorption-Measurement" instrument is using another measuring principle. A larger measuring size and a waiver of a measuring pressure results in a lower scatter and a higher accordance to standard test.

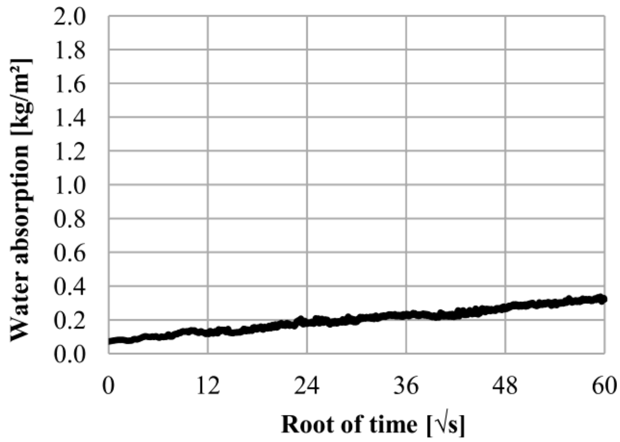

Figure 11. Raw data of „Water-Absorption-Measurement" instrument at testing described masonry façade, resulting A_w value is 0.004 kg / (m² × √s).

6 CONCLUSION

In this paper, the relationships and the problems of wind-driven-rain-resistance and water absorption coefficient of masonry façades are briefly explained. Following is a presentation of known in-situ test methods for determining the water absorption coefficient. Subsequently, the developed „Water-Absorption-Measurement" instrument is presented. The composition, the measurement principle, the measurement process and the measurement evaluation of the developed instrument are discussed. Subsequent are results from laboratory and field experiments.

The developed „Water-Absorption-Measurement" instrument allows non-destructive determination of the water absorption coefficient of masonry façades. The gravimetric measuring system reaches a repeatable accuracy up to $\pm 8.3 \times 10^{-4}$ kg / ($m^2 \times \sqrt{s}$). Especially on fair-faced masonry a representative sample about 0.40 × 0.51 m is tested.

In cooperation with a local partner, the University of Applied Sciences in Leipzig also developed a version of the „Water-Absorption-Measurement" instrument which is ready for series production. The "WAM 100 B" is a bit smaller than the prototype. In Figure 12 the "WAM 100 B" is shown during a measurement.

Figure 12. Further development of „Water-Absorption-Measurement" instrument, ready for series production version, WAM 100 B.

For the WAM instrument a mainly usage is to check the existing wind-driven-rain resistance in light of planning an inside insulation on historical fair-faced masonry façades. In practice the WAM instrument can be used for preliminary investigation or quality control for renovating masonry facades. For example after finishing a hydrophobic impregnation the created effect can be checked. Furthermore the optimal solution for renovating a masonry façade can be selected by using different test surfaces. The measured values also can be used for research and development as input for simulation programs.

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