Application of electrical impedance spectrometry for measurements of humidity distribution in aerated concrete masonry constructions

S. Rubene, M. Vilnitis

***Abstract*—** In time when one of the most important construction trends is sustainable construction as well as cost saving on heating and cooling of buildings, it is important to acknowledge the possibilities of application of construction materials with high heat parameters and the ways in which these parameters can be obtained. Autoclaved aerated concrete (AAC) is a load bearing construction material, which has high heat insulation parameters, although it has one significant problem. If the autoclaved aerated masonry construction has high moisture content then it loses its heat insulation properties. This is the reason why it is important to detect the humidity distribution throughout the cross section of the masonry elements in order to conduct the drying process of the aerated concrete construction. Electrical impedance spectrometry (EIS) can be applied for monitoring of drying process of the masonry constructions and detecting of humidity distribution throughout the cross section of aerated concrete masonry constructions. Research of correlation between EIS measurements on autoclaved aerated concrete masonry blocks and absolute values of humidity content in the masonry blocks has been described in this paper.

***Keywords*—** aerated concrete, EIS measurements, humidity distribution, non-destructive testing.

I. INTRODUCTION

AERATED concrete is a load bearing construction material, which has high heat insulation parameters. It can be used for constructions with high heat insulation parameters. In separate cases no additional heat insulation on the wall constructions is necessary if the aerated concrete masonry is used as a wall construction material. The most common problem of autoclaved aerated concrete heat insulation properties is high percentage of humidity content which is distributed throughout the cross section of the masonry elements. The second problem is a proper and conducted drying process of the masonry construction. In case the AAC masonry construction has not reached the air-dry state and is covered with finishing layers such as cement mortar on the internal side of the building or additional heat insulation layer with finishing layer on the external side of the wall the heat resistivity values of the construction can be much lower than calculated.

In order to avoid such problems it is necessary to monitor the drying process of autoclaved aerated concrete masonry construction.

Electrical impedance spectrometry (EIS) is applied for monitoring of drying process of the masonry constructions and for detection of humidity distribution throughout the cross section of AAC masonry constructions. Research of correlation between relative measurements of humidity distribution and absolute values of moisture content % in the AAC masonry construction is described in this research.

II. PROBLEM FORMULATION

A. The problem of moisture migration in autoclaved aerated concrete masonry constructions

Construction process is performed in short terms and several significant problems are affecting the quality of the erected buildings and their heat insulation parameters. The problem of increasing the efficiency of heat insulation's quality is significant in northern countries where the average temperature drops below 0°C in winters. Researches on improvement of the heat insulation installation technology have been performed by Liisma et.al [10] and optimal boundary control in thermal fluid dynamics by Cerroni et.al. [11]. In particular the main reason why monitoring of heat and moisture transfer processes as well as the monitoring of the drying process itself in AAC masonry constructions is so important is the fact that the optimal heat insulation parameters of this material can be obtained only in dry state. Non-destructive monitoring (NDM) of these processes is the best option for long term data obtaining and comparison of the obtained information. NDM can be used in habitable buildings and influence of different aspects on constructions` drying processes such as influence of heating regime or impact of weather conditions can be considered in the results.

That is the reason why non-destructive monitoring method – electrical impedance spectrometry (EIS) is chosen for

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monitoring of the AAC masonry drying process. The method has proven itself as useful and applicable as a relative measurement method where the obtained electrical resistivity measurements provide overall impression about the changes of the humidity distribution throughout the cross section of the masonry construction. It means that the measurement results are obtained as electrical resistivity values, which change as the moisture content of the construction changes. A question about correlation between the resistivity values and absolute values of moisture content in the construction is open. It means that a research in this area has to be done. The results of such research are presented in this paper. A previous research in this field has been performed by the authors [12] where primary correlations between the EIS measurements and humidity rate of the AAC masonry constructions has been established.

B. Measurement methods for detection of humidity distribution in construction materials

Methods, which are applied for detection of humidity distribution and detection of moisture content or water saturation rate of the construction materials, can be divided into two general subgroups – destructive methods and non-destructive methods.

As the most popular destructive testing method can be stated the gravimetric method. Gravimetric method consist on determining water content through weighting samples upon oven drying, encompassing absorbed and chemically bound water (1).

$$W = \frac{m_w - m_d}{m_d} \cdot 100\% \quad (1)$$

W-saturation rate of the material %;
m_w-weight of the material sample in wet state, g;
m_d- weight of the material sample in dry state, g.

It can provide data about average moisture content of the construction material if the weight or density of the material in dry state is known. The negative aspect of this method is the fact that for each measurement a sample must be taken from the construction and it means that long term monitoring by this method is problematic if the monitoring is performed in building in the construction phase or in already habitable building.

Application of gravimetric method for detection of moisture content rate of has been widely researched by Akita et.al [15], which proposed the analysis of prismatic concrete specimens in order to quantify the moisture transfer experimentally and numerically (Fig. 1). Variations in water content were measured in different depths by splitting the specimens and comparing the mass of each peace before and after oven drying at 105°C. [13].

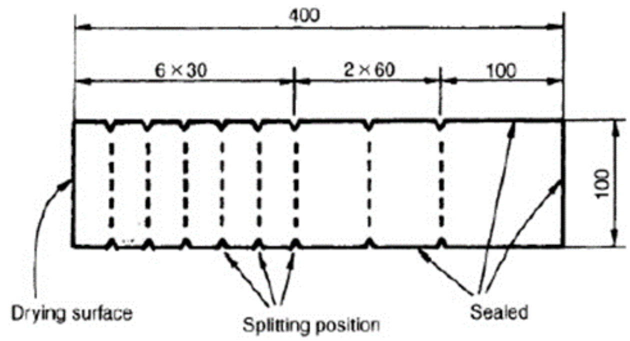

Fig. 1 Dimension (mm) of specimens subjected to one-face drying [12], [13]

Such approach can provide credible results about humidity distribution throughout the cross section of the construction but it is long and laborious process, which is hard to repeat in many places on construction site. However, this method can be used for controlling of the non-destructive test results [14].

A range of non-destructive testing methods for moisture content measurements of the construction materials can be applied as well.

A research on different non-destructive measurement methods for detection of moisture content in construction materials was performed by G.Quincot, M.Azenha, J.Barros and R.Faria in framework of project "RELATÓRIO REFERENTE AO PROJETO PTDC/ECM/099250/2008" [1]. Further there are described few methods which can be applied for detection of humidity distribution throughout the cross section of the autoclaved aerated concrete material.

The gamma densitometry is a non-destructive testing method commonly used to control the density of civil engineering materials [1-2].

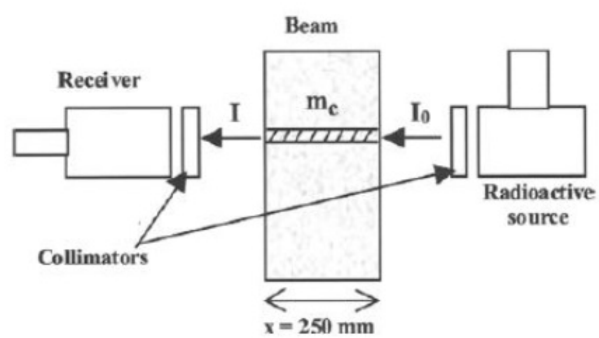

Fig.1 Principle of the gamma densitometry technique [1]

The principle of this method (Fig.1) is based on a beam of gamma rays emitted by radioactive source and passing through the concrete. The relative intensity of the transmitted particles is related to the mass of the traversed material m_c, the mass variation of the traversed points can thus be measured. Since chemical evolutions do not lead to significant losses of mass, the mass variation in these beams stem solely from water evaporation; and can be interpreted as the profile of water content variations [1] [3].

Another method for detection of moisture content in construction materials is use of relative humidity sensors. High quality relative humidity sensors are usually made of hair from horses or humans. The movement of the hair is converted into an electrical signal by a strain gauge. Similar sensors are made of a strip cellulose butyrate, a water absorbent polymer that likewise stretches and shrinks according to relative humidity.

There are two main types of relative humidity sensors, capacitive and resistive sensors (Fig.2). The capacitive sensor consists of a thin layer of water absorbent polymeric or inorganic material that is coated onto a conductive base. This layer is then covered with porous conductive layer material. With the increase of the relative humidity, the water content of the polymer increases too. Water has a high dielectric constant, which means that the combination of two electrodes with the water between can store a relatively high electric charge.

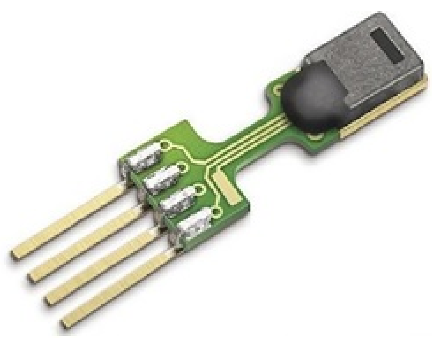

Fig. 2 (a) Capacitive sensor [1]

Fig. 2 (b) Resistivity Sensor [1]

Electrical capacity is measured by applying rapidly reversing (AC) voltage across the electrodes and measuring the current that passes. The polymer or inorganic material is usually aluminum oxide and just plays an indirect part of the measurement. The change of capacitance of these capacitive sensors is, however, small when even compared with the capacitance of few meters of cable. This means that the electronic process of data acquisition has to be completed close to the sensor. If one data logger is connected to several relative humidity sensors, each sensor will need its own power supply and relatively bulky electronics [1] [4].

Electrical impedance spectrometry (EIS) is one more non-destructive measurement method for detection of humidity distribution throughout the cross section of constructions, which is based on electrical measurements.

The EIS is based on the periodic driving signal – the alternating signal. If low amplitude of the alternating signal is used, concentration changes of charge are minimal at the surface of an electrode connected with the measured surface, which is very important in systems sensitive to so called concentration polarization. The range of frequencies used for the driving signal enables the characterization of systems comprising more interconnected processes with different kinetics.

EIS has been applied of detection of humidity rate in concrete constructions by Rajabipour and Weiss [17-19]. The method in these researches was viewed from the perspective that the electrical resistance of the concrete depends not only on it humidity state but on such factors as the porosity, hydration of the concrete and temperature of the sample as well. In those experiments embedded humidity sensors were applied on the concrete samples for detection of humidity rate inside the construction.

In the Laboratory of Water – Management Research of the Institute of Water Structures at the Civil Engineering Faculty of Brno University of Technology, a measuring instrument with a Z-meter III device (Fig.3) has been developed within the solution of an international project E!4981 of programme EUREKA. This instrument is verified in laboratory experiments and measurements on objects in situ [5-6].

Experiments with EIS method for the detection of humidity distribution throughout cross section of aerated concrete constructions have been performed in Riga Technical university by Z-meter III device and methodology for measurement process is being developed [6-8].

Fig.3 Z-meter III device with measurement probes and main interfaces [7]

The positive aspect of this device is the possibility to embed and withdraw the measurement probes after the measurements have been taken. Therefore it is possible to perform a range of EIS measurements by using one or several probe pairs, which allows to extend the possibilities of EIS application in on-site measurements.

C. Previous research on humidity distribution measurements in aerated concrete constructions by EIS method

Previous research in field of EIS application on detection of humidity distribution throughout the cross section of AAC masonry constructions by application of Z-meter III have been performed at Riga Technical university [6]. The researches include such aspects as impact of contact surface between the measurement probe and the measurement surface on the measurement results [13], the impact of the masonry joints on the measurement results [14]. These are important factors to be considered because it is important to discover all impact factors on the EIS measurements prior correlating the obtained electrical resistivity results to the moisture content values of the construction.

These researches show that in relative means the EIS spectrometry provide credible results for measurement of humidity distribution changes throughout the cross section of AAC masonry blocks. The relative nature of these measurements is based on the fact that the direct measurement is based on electrical resistivity measurements and the changes of the electrical resistivity can be correlated with changes of moisture content in the construction.

Previous researches performed by authors [7-8] show that several significant factors must be taken into consideration during the application of EIS on humidity distribution measurements. The facts to be considered are cracks in the construction between the measurement points and the fact that between the test series the measurement probe holes must be sealed to avoid fast drying of the measurement segment and thus obtaining incorrect measurement data on drying process. The surface of the AAC material which is exposed to surrounding environment has significantly higher drying speed than its inner structure therefore this fact can have a significant impact on overall measurement results.

III. Correlation between EIS measurements and humidity distribution in aerated concrete masonry constructions

It is important not only to see relative changes of humidity distribution throughout the cross section of the masonry element (in this case AAC masonry block) but also to be able to correlate the values of relative measurements to absolute values of material's moisture content rate. Manufacturers of the masonry elements state their material properties in dry or air-dry state and therefore these are the values which are operated in heat efficiency calculations. It means that prior beginning of finishing works the humidity level of the construction must be measured and the actual humidity rate of the construction must be determined. In opposite case significant differences between calculated and actual heat insulation properties can rise because in cases when the cladding is performed with blocks containing high humidity rate the masonry construction cannot reach the air dry state if the finishing layers are laid on both surfaces of the masonry construction immediately after the masonry cladding has been finished.

A. Description of the experiment

In order to find correlation between electrical resistivity measurements by EIS and moisture content values of the construction a following experiment was performed.

In the experiment two types of autoclaved aerated concrete blocks (AEROC universal [9] and Texoblock standart [16]) as in Fig.4 were used.

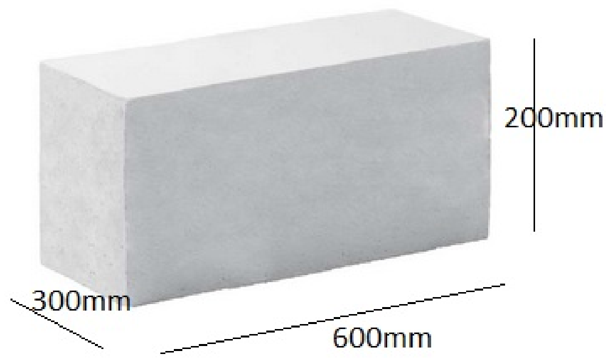

Fig.4. Aerated concrete block AEROC Universal [12]

Each of the blocks was cut in three identical parts with part size of 200mm x 200mm x 300mm. In each sample two holes with 12mm diameter for measurement probes were drilled as in Fig.5.

For the measurements of humidity distribution, one pair of measurement probes with five active channels was used. The probes were inserted into the drilled holes as in example on Fig.6.

Fig.5. Aerated concrete block fragments with bores for measurement probes

Fig.6. Example of measurement insertion in aerated concrete block fragment

The measurements were taken between the active parts of measurement probes. The active channel of the probe is the metallic element on the probe (see Fig.6). Measurements are performed between corresponding channels of two probes which allow to measure resistivity in different layers of the construction within the same measurement. In particular case all five channels of the probe were used for the measurements in the construction.

In order to monitor the drying process of the blocks each time they were scaled, the changes of weight were fixed and the resistivity measurements by EIS performed (Fig.7). After the blocks had dried naturally, they were inserted into oven in 105°C degree temperature to reach an absolute dry state. EIS measurements were performed on absolute dry state as well. After these measurements the moisture content rate of the material was calculated using the gravimetric method (1).

As a result of the experiment it became possible to compare the measurement results and correlation lines for two different types of autoclaved aerated concrete masonry blocks. This comparison allowed to make conclusions whether the EIS measurement results by Z-meter III display the same deviations in the measurement results due to the slightly different pore structure of the concrete material as it was displayed in [20] tests by sensors used by Rabijapour and Weiss as well as Barsotelli et.al [21].

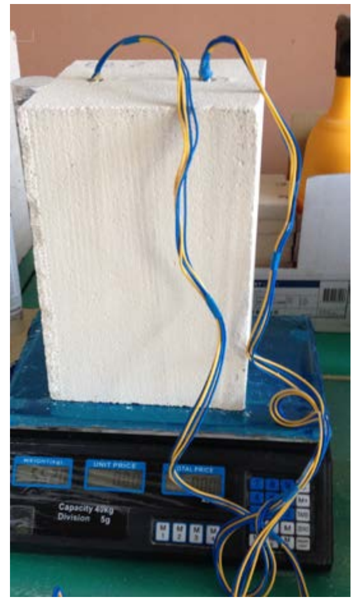

Fig.7. EIS measurements in aerated concrete block fragment (C1-1 to C3-3)

B. Results of the experiment

As a result of the experiment six independent correlation equations were determined. The correlations are displayed in Fig.8., Fig.9 and Fig.10.

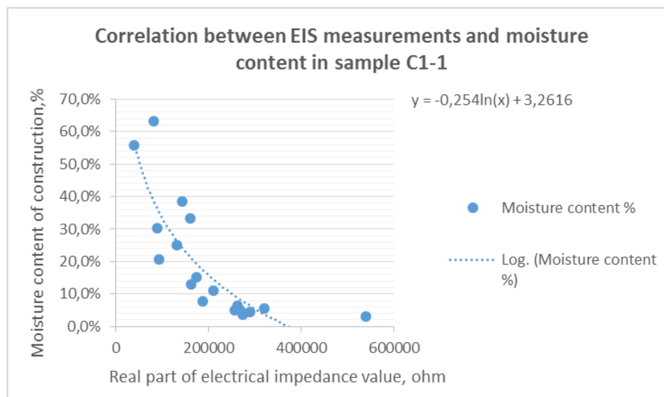

Fig.8. Correlation between EIS measurements and moisture content % in aerated concrete block fragment (C1-1)

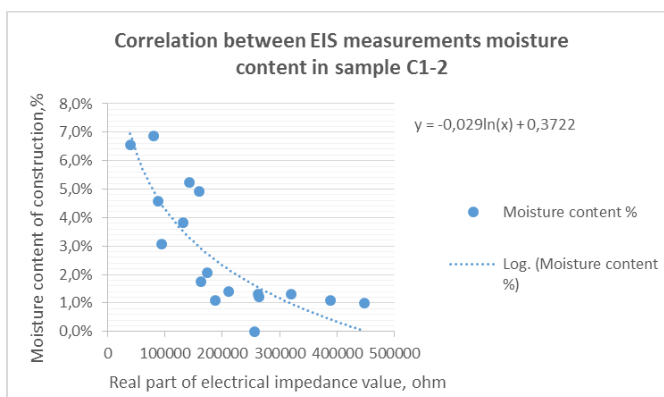

Fig.9. Correlation between EIS measurements and moisture content % in aerated concrete block fragment (C1-2)

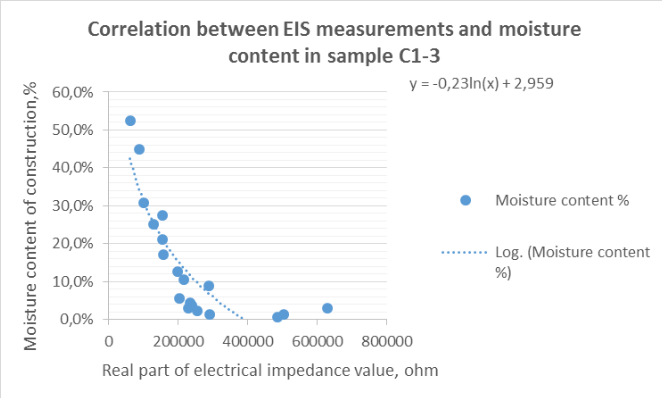

Fig.10. Correlation between EIS measurements moisture content % in aerated concrete block fragment (C1-3)

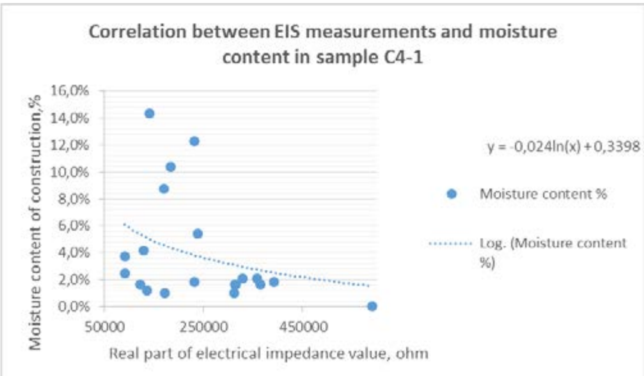

Fig.11. Correlation between EIS measurements and relative humidity % in aerated concrete block fragment (C4-1)

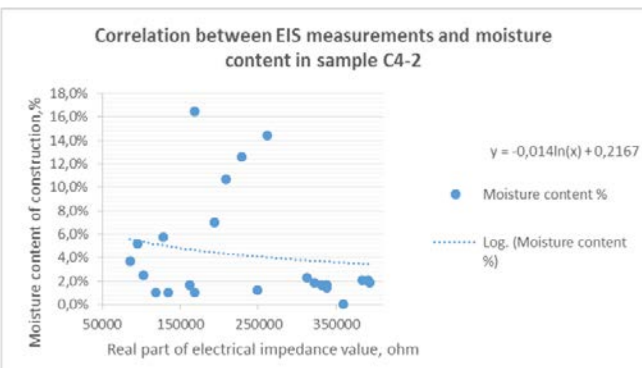

Fig.12. Correlation between EIS measurements and relative humidity % in aerated concrete block fragment (C4-2)

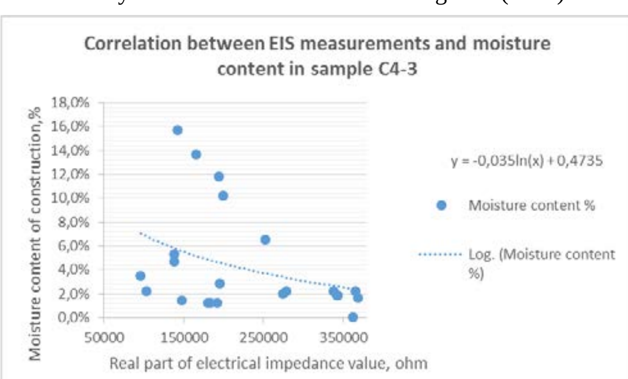

Fig.13. Correlation between EIS measurements and relative humidity % in aerated concrete block fragment (C4-3)

After comparison of obtained results it is clear that the density and pore structure of the AAC masonry block has significant impact on the measurement results. Correlation between EIS measurement results and the relative humidity of the construction has logarithmic character but absolute values can be compared only if the measurement conditions, especially, the structure of measured AAC material is similar. Results in Fig.8 to Fig.10 show similar character as well as the results on Fig.11 to Fig.13. As the samples C1-1 to C1-3 were from one type of AAC masonry block [9] and samples C-1 to C4-3 were from the other type of AAC masonry block [16] then it is possible to conclude that density and other physical characteristics of the material have significant impact on the electrical measurement results. Therefore, the overall application of the EIS measurements for humidity distribution measurements is restricted to the types of the AAC which have previously established correlation equations between EIS measurements and humidity rate of the construction.

It means that for each type of AAC masonry blocks there should be developed individual correlation equation between EIS measurement results and moisture content of the material. Moreover, the type of the AAC should be recognized during the EIS measurements, in opposite case it may lead to the situation when wrong correlation equation is chosen and the obtained EIS measurement results are wrongly interpreted.

IV. Conclusion

EIS measurements can be applied for on site measurement of humidity distribution throughout the cross section of autoclaved aerated concrete masonry constructions. Correlation between EIS measurements and moisture content of the construction material have been established and it has logarithmic character. The correlation equation depends on the structure of the relevant AAC material but overall this correlation has logarithmic character and can be used as a reference material for further on site measurements of humidity distribution by EIS measurement device Z-meter III.

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