Abstract

Electrical impedance spectrometry (EIS) is applied for detection of humidity distribution throughout the cross section of autoclaved aerated concrete masonry constructions. It is a non-destructive method, which is easily applicable on-site and provides wide range of information about moisture migration through the cross section of a construction and about changes of materials porous structure. The particular research provides data about influence of direction in which the measurements are performed (parallel or perpendicular to supposed cladding direction) on the results of the frequency analysis and measurement values. All measurements are performed on autoclaved aerated concrete masonry blocks.

Keywords: EIS, non-destructive testing, humidity distribution, drying process, autoclaved aerated concrete

1. Introduction

Autoclaved aerated concrete (AAC) is a load bearing construction material with high performance of heat insulation parameters. In order to reach these high heat insulation parameters stated by the manufacturers it is necessary to control the drying process of the construction in order to avoid situations when the drying is slowed down by application finishing layers on the surface of AAC masonry blocks.

As it is commonly known the AAC masonry blocks have slightly different insulation properties depending on the manufacturing direction of the blocks. These differences are caused by the specialties of the manufacturing technology and the following uneven distribution of pores in different directions of the masonry blocks. The subject of the research described in this paper is to determine the impact of the EIS measurement direction on results of frequency analysis and measurement values of AAC masonry constructions.

2. Methodology

2.1. EIS method

Method of electrical impedance spectrometry (EIS) enables detection of the distribution of impedance or other electrical variables (such as resistivity, conductivity etc.) inside a monitored object, and thus the observation of its inner structure and its changes [1], [2]. This method ranks among indirect electrical methods and it is used in measuring properties of organic and inorganic substances. It constitutes a very sensitive tool for monitoring phenomena that take
place in objects (e.g. changes occurring in earth filled dams when loaded by water, in wet masonry sediments etc.),
electrokinetic phenomena at boundaries (e.g. electrode/soil grain, between soil grains) or for describing basic ideas
about the structure of an inter phase boundary (e.g. electrode/water) [3]. The range of frequencies used for the driving
signal enables the characterisation of systems comprising more interconnected processes with different kinetics [4],
[5].

The basic property of electrical impedance is characterization of AC electrical circuits. It is always greater than or
equal to the real electrical resistance $R$ in the circuit. Imaginary resistance, i.e. inductance reactance of inductor $XL$
and capacitance reactance of capacitor $XC$, creates variable and therefore frequency dependent part of the
impedance. Electrical impedance is evidently made up of real and imaginary parts. Resistance $R$ creates real part and
is frequency-independent. Imaginary part is created by reactance $X$, which is frequency-dependent. Electrical
impedance can be expressed by Ohm’s equation for AC circuits [6].

2.2. Z-meter III device

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 has been developed within
the solution of an international project E4981 of programme EUREKA. This instrument is verified in laboratory
experiments and measurements on objects in situ [4], [5], [7].

Z-meter III device consists of an electronic block which performs all measurement procedures. Measurement probes
are attached to the electronic block. There can be used single probe or a pair of probes for the measurements.

The output data of EIS measurements are divided into components of electrical impedance – the $R$ and the $X$
parts are separated in the output data which brings more opportunities for data interpretation.

As the measurements are taken in AC then the measurement frequency can be altered from 1 000 to 20 000Hz. The
measurement settling time as well as the number of repetitions can also be set in the settings of the device.

3. Previous research in field of EIS application on AAC masonry constructions

Initially, the EIS measurements by Z-meter III were applied on soils and earth filled dams [8]. Researches of
application of EIS measurements on AAC masonry construction were started by authors in 2013.

Prior the EIS measurements have been applied for the detection of moisture content in concrete constructions by
Rajabipour and Weiss [15], Schießl and co-workers [16] have also researched the moisture gradients that develop in
drying concrete. These researches have been performed on concrete constructions and show credible results on
application of EIS measurements for detection of moisture content in concrete material. The main difference between
the concrete and AAC is the porous structure of the material which has significant impact on water absorption
parameters as well as on electrical behavior of the material.

Therefore, prior application of EIS measurements on AAC construction a frequency analysis should be performed
in order to determine which frequency is most suitable for the respective material. Previous researches prove that a
selection of a correct measurement frequency can have a significant impact on the measurement results. If unsuitable
frequency is selected, the monitored changes of humidity distribution can be minimal or cannot be monitored at all. It
is important to pay attention not only to a single frequency which seems to be suitable for the measurements but also
to a range of frequencies around the selected frequency. This is an important fact due to the fact that the moist suitable
frequency tend to change its value along with changes of AAC structure changes during its drying process [5].

First researches of authors in field of application the EIS measurements on AAC masonry constructions were started
with measurements on single masonry block [5].

After the correlation between the EIS measurements within the block were established and the assumed correlations
between the humidity ratio and changes of the electrical resistivity values were confirmed further researches were
started in order to develop an on-site applicable non-destructive test method for detection of humidity distribution
throughout the cross section of AAC masonry constructions.

These researches display relative correlation between the changes of humidity ratio throughout the cross section of
the construction and EIS measurement results [5], [9], [10], [11]. As one of the main fields of research the monitoring
of the AAC masonry wall drying process by EIS was performed [10], [11]. The results of the monitoring process
proved that in relative values it is possible to monitor moisture migration through the cross section of AAC masonry
constructions.
As the main correlations were established the question of the impact of masonry joints or large masonry cracks arouse. For this reason the second set of experiments was performed. The first research displayed that masonry joints and cracks have significant impact on the EIS measurement results (Fig.1). Thus the EIS method is not applicable on masonry constructions where masonry joints or large cracks are between the measurement probes without further researches [9].

The impact of the masonry joint on the values of EIS measurements can be described with linear correlation (1) between measurement results which are obtained in boundaries of single masonry block and results where a masonry joint is between the measurement probes.

\[ y = ax + C \]  

(1)

The a quotient is in range of 0.67 to 0.96 that mean the impact factor of joint is in the same range accordingly to base measurement value in section without joints. However, the C constant is different every time and it is difficult to conclude what it depends on. The value of C constant has to be a subject of further research [12].

![Fig.1 EIS measurement results with masonry joint impact in a masonry wall fragment [12]](image1)

![Fig.2. Correlation between EIS measurements and relative humidity % in aerated concrete block [13]](image2)

After the research of monitoring the humidity migration through the cross section of AAC constructions in relative means was completed, a research of correlation between the electrical resistance values of EIS measurements and relative humidity rate of the measured material was performed [13].

The research allowed to establish correlation between the EIS measurement results of real part of electrical resistance in ohm (\(\Omega\)) and the relative humidity value of the AAC material in percentage (%) (Fig.2).

Another issue, which should be considered is the impact of the manufacturing direction of AAC on the EIS measurement results. As the measurements are performed on wall fragment it is important to consider the AAC masonry block cladding direction. AAC masonry blocks can be used for cladding in both possible ways – on its side edge or on its plane edge. The load bearing capacity does not change in this situation but as the aerated concrete masonry blocks are not totally isotropic material – due to the specialties of the manufacturing process they have different distribution of pores in different directions of the block volume. These differences may have impact on EIS measurement results and the research about such impact was performed by authors in Riga Technical university.

4. Description of the experiment

In the experiment two fragments of the same AAC block were used (AEROC universal AAC masonry block [14]) with density of 375 kg/m\(^3\). In both blocks a pair of bores were made for insertion of measurement probes (Fig.3). In one block the bores were made parallel to the manufacturing direction of the block (block A1) and in the other block perpendicular to the manufacturing direction of the block (block A2).

The EIS measurements were performed with 4 channels of probe for A1 block and 5 channels for A2 block. The difference of the channels were caused by the thickness of the blocks and the fact that in A1 block only 4 channels could be inserted (Fig.4).
At the first phase of the experiment the frequency analysis for both blocks was performed. The frequency analysis was performed in range from 1 000Hz to 20 000Hz with measurement step of 100Hz. Afterwards the results were processed in order to determine the most suitable frequency range for further measurements.

The second phase of the experiment consisted of several parts. At first, both blocks were fully saturated with water and the initial EIS and gravimetric measurements were taken. Afterwards blocks were left for drying in laboratory conditions (+20…+25°C and approx. 70% Rh) and periodically EIS measurements were performed on the blocks. After the blocks had reached an air dry state they were put into a drying oven and dried to absolutely dry condition in compliance with RILEM recommendations for drying of AAC [17]. Afterwards another set of EIS measurements were taken. During all time of the EIS monitoring of the blocks they were also scaled so that correlation between the EIS measurement values and the average humidity ratio in % of the material could be established.

5. Results

5.1. Results of frequency analysis

A separate frequency analysis was performed for each block. For frequency analysis the X component of resistance was used because the measurement frequency depends on the porous structure of the material. As the porous structure of the AAC tends to change with the changes of the moisture content in the material, it is important to consider the anisotropic properties of the ACC within the frequency analysis of the material. The results show that the most suitable frequencies for different measurement directions vary significantly (Fig.5 and Fig.6).

For the A1 block the most suitable measurement frequency is in range from 8 000 – 13 000Hz but for block A2 it is a range from 5 000 – 9 000Hz. In order to obtain a comparable measurement results there had to be chosen one measurement frequency which in this case was chosen 8 000Hz.
Attention should be paid to the 2 000Hz frequency in both graphs (Fig.7 and Fig.8) because this frequency shows that next to a seemingly suitable measurement frequency can be frequencies which are totally unsuitable for the measurements in particular material. If such unsuitable frequencies are chosen for measurements all test results can be compromised because of the drying process’ impact on the application of certain frequencies for EIS measurements.

5.2. Results of measurement values

After determination of the measurement frequency the monitoring process of the AAC blocks begun. The EIS measurements were taken for four months time and impact of measurement direction was determined (Fig.7).

![Fig.7 Comparison of EIS measurement data on blocks A1 and A2 depending on measurement direction](image)

The measurement results show that at the beginning of AAC masonry blocks’ drying phase the measurement values do not significantly differ but as the drying process progresses the influence of optimal frequency distribution displays its impact on the results and the measurement values start to differ significantly. It means that in situations when comparison of the EIS measurement results is necessary it is important to take into consideration the measurement direction. In opposite case the obtained results can be misinterpreted as increased speed of moisture migration through the cross section of the construction.

5.3. Correlation between measurement values and relative humidity rate of the construction material

In order to develop the application possibilities of EIS monitoring a correlation between EIS measurements and relative humidity values have been determined (Fig.8 and Fig.9).

The correlations equations differ depending on measurement direction but overall the trend of the equations is similar and allow to assume that in all cases concerning measurements performed on AAC masonry constructions they would be similar.

![Fig.8 Correlation between EIS measurements and relative humidity values in % for sample A1](image)

![Fig.9 Correlation between EIS measurements and relative humidity values in % for sample A2](image)
The correlation between the EIS measurement values and relative humidity rate of the construction is logarithmic.

The developed correlation formulas and graphs allow starting on site experiments of humidity distribution detection throughout the cross section of AAC masonry constructions.

6. Conclusion

EIS method can be applied for on site measurement of humidity distribution throughout the cross section of AAC masonry constructions. Correlation between EIS measurements and relative humidity of the construction material have been established. The measurement direction in correlation to the manufacturing direction of the relevant AAC material has significant influence on absolute values of the measurement results. It means that prior the application of EIS measurements it is necessary to determine the direction of cladding in masonry construction as it can have significant influence on test results. The developed guidelines for frequency analysis and correlations between EIS measurement results and relative humidity ratio in construction can be used as a reference material for further on site measurements of humidity distribution by EIS measurement device Z-meter III.

References