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Monitoring of concrete hydration by electrical measurement methods

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Abstract

Analysis of impedance spectra of inhomogeneous materials is a part of the impedance spectroscopy which is still waiting for its development. Materials having higher electric resistance values (over 500 kΩ) can be considered – under certain simplifying assumptions – as dielectrics. A theory of dielectric polarization was formulated by Debye for homogeneous materials. Concrete setting and hardening determine the concrete quality. The impedance spectroscopy method, as one of the non-destructive testing method group, was used to characterize concrete specimens and track the changes in the concrete spectrum during the hydration process. Variances in the loss factor versus frequency $\tan \delta (f)$ and impedance imaginary component Im (Z) versus impedance real component Re (Z) of the specimens under investigation have been observed. The specimen quality has been described by means of the loss type prevailing in the material. The results of this study are expected to provide information about the correlation between the n-factor (curve parameter obtained from Cole-Cole diagram) and the concrete setting time. At present, one is not able to determine unambiguously the individual material component contributions to the total electric conductivity and polarization at various frequencies of the exciting field.

Keywords: Impedance spectroscopy; dielectric losses; loss factor; conductivity losses; polarization losses; hydratation; concrete

1. Introduction

The impedance spectroscopy is a non-destructive testing method, which uses the impedance characteristic frequency dependence to analyse the properties of the material [1]. The experiment set-up designed to study the

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system under investigation includes: a metal-material-metal network, which is relevant for identifying the application limits of the impedance spectroscopy method. The method cannot be applied to thick-layer low-conductivity materials. Reinforced concrete products may serve as an example. The principle of the mentioned method is based on evaluation of the dielectric losses versus frequency plots. The dielectric losses of composite materials and plastics can assume values which are many times higher than those of the most materials commonly used in the building industry.

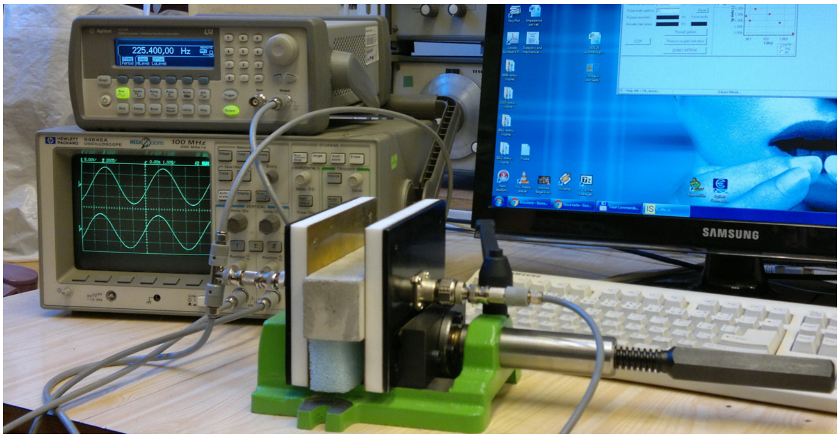

Fig. 1. Measuring set-up and one of specimens: AC power supply, specimen under test, double-channel oscilloscope [1] (illustrative image).

Analysis of impedance spectra of inhomogeneous materials is a part of the impedance spectroscopy, which is still waiting for its development. At present, one is not able to determine unambiguously the individual material component contributions to the total electric conductivity and polarization at various frequencies of the exciting field. Materials having higher electric resistance values (over 500 kΩ) can be considered – under certain simplifying assumptions – as dielectrics. A theory of dielectric polarization was formulated by Debye [2] for homogeneous materials. However, experiments carried out on real materials and the respective conclusions did not show to be in agreement with the fundamentals theories. K S Cole and R H Cole and, also, Fuoss and Kirkwood, started from the Debye’s theory to derive models of a dielectric which appear to fit experiment results and conclusions [3] more closely. The behavior of a dielectric in an AC electric field is best described in terms of the complex relative permittivity. Debye has derived a formula for the complex relative permittivity, ε^*, of weakly polar liquid dielectrics, as follows:

$$\varepsilon^*(j\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j\omega\tau}. \tag{1}$$

Here τ is the relaxation time, independent of the time, however dependent on the temperature, ε_S - static permittivity (frequency $\to$ 0 Hz), ε_∞ - optical permittivity (frequency $\to \infty$ Hz), angular frequency $\omega=2\pi f$, f - frequency of the exciting electric field [4].

Following equation holds for the loss factor tan δ:

$$tg\delta = \frac{\varepsilon''(\omega)}{\varepsilon'(\omega)} = -\frac{(\varepsilon_S - \varepsilon_\infty)\omega\tau}{\varepsilon_S + \varepsilon_\infty \omega^2 \tau^2}. \tag{2}$$

There are several different relaxation times in a real dielectric. Their distribution is described by a distribution