Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 151 (2016) 236 – 240
Procedia Engineering
www.elsevier.com/locate/procedia

International Conference on Ecology and new Building materials and products, ICEBMP 2016

Carbon admixtures influence on the electrical properties of slag mortars focusing on alternating conductivity and permittivity

Miroslav Lunak*, Ivo Kusak, Zdenek Chobola

Institute of Physics, Faculty of Civil Engineering, Brno University of Technology, Veveří 95, 60200 Brno, Czech Republic

Abstract

New materials based on alkali-activated slag mortars may be an important contribution of applied research, which strives to offer the use of waste materials as a full replacement for the currently used binders and explores the impact of forms of carbon incorporation on the physical and mechanical properties. The influence of graphite powder addition on the electrical properties of alkali-activated slag mortars was investigated. 1–10 wt. % of graphite powder (with 1 % step) was incorporated into the mortar and the electric resistance spectra, permittivity and loss factor of the prepared prismatic samples were measured. The unique Vector analyzer R&S ZNC with a coaxial probe DAK-12 from Speag was used to determine permittivity and loss factor, electrical resistance was measured using two channel oscilloscope. Higher content of graphite powder increases the electrical conductivity, which makes the tested materials more sensitive and measurable via electromagnetic methods. The most striking change in the relative conductivity was observed at excitation frequency of the external electric field of 10 kHz. At high frequencies electrical excitation field 10 MHz to 3 GHz were determined by vector analyzer value of the real part of permittivity, which fell from the 20 to the 4. Dissipation Factor shows in his semi arc spectrum a peak at 1.2 GHz. These measurements are among the building materials still little used and open new possibilities of diagnostics.

Keywords: Electric measurement; alkali-activated slag; building materials; carbon admixtures; dissipation factor;

* Corresponding author. Tel.: +0-420-541-147-659.
E-mail address: lunak@dp.fce.vutbr.cz

doi:10.1016/j.proeng.2016.07.359

1. Introduction

Aluminosilicate production of non-clinker binders is one possible suitable utilization of waste substances. Alternative binders based on alkali activated slag were used in concrete production since the second half of the 20th century, especially in Eastern Europe, Scandinavia and China.

Various kinds of slag can be used, e.g. blast or steel furnace slag, slag from casting of non-ferrous metals and other slags with high content of amorphous phase. These slags have latent hydraulic properties, which can be activated with a suitable activator. As activators are used mostly silicates, hydroxides and carbonates of a sodium or of potassium.

There are good results in the chemical industry with mixing carbon powder into many materials. Carbon provides firming and greater durability of materials.

This paper presents the basic electrical properties of laboratory prepared alkali-activated composite materials based on slag with the addition of different amounts of micronized natural graphite. [4,5,6]

Impedance spectroscopy (IS) is a non-destructive testing (NDT) method ranking in the electrical engineering measuring method group. It outputs data providing information on material electric and dielectric properties. Microscopically inhomogeneous materials are frequently used in the building industry. Unfortunately, the impedance spectroscopy results and their characterization on the basis of this method are not unambiguous. [1]

Admixture of carbon powder should give different electric properties by using alternating electric field than obvious cement based paste.

2. Material used

Alkali-activated finely ground granulated blast furnace slag was chosen as a binder. Activation was carried out by water-glass solution, Susil MP 2,0. As filler were used both test norm-sand (0-4 mm) and carbon powder Cond 896. Triton X-100 was used to treat the graphite surface and defoaming agent Lukosan S was added to minimize the gas content. The compositions of each mixture are summarized in Table 1.

Table 1. Recipes of mixtures of specimens.

Components / COND	Ref	1%	2%	3%	4%
slag (*g*)	450	450	450	450	450
Susil (*g*)	90	90	90	90	90
sand (*g*)	1350	1350	1350	1350	1350
COND 8 96 (*g*)	0	4.5	9	13.5	18
0.5% Triton X-100 (*ml*)	0	30	30	30	30
1% Lukosan S (*ml*)	0	5	5	5	5
water (*ml*)	185	150	155	160	165

Components / COND	5%	6%	7%	8%	9%	10%
slag (*g*)	450	450	450	450	450	450
Susil (*g*)	90	90	90	90	90	90
sand (*g*)	1350	1350	1350	1350	1350	1350
COND 8 96 (*g*)	22.5	27	31.5	36	40.5	45
0.5% Triton X-100 (*ml*)	60	60	90	90	120	120
1% Lukosan S (*ml*)	10	10	15	15	20	20
water (*ml*)	135	140	110	115	85	90

Mixing method: Water-glass Susil and Triton treated graphite powder were put together with a part of water (about 100 ml) and stirred in a mixer for 1 min. Then the slag, sand, the rest of the water and Lukosan S was added and stirred for another 1 min. After being unmoulded, the samples were stored in water for 28 days and then 7 days in standard laboratory conditions for the moisture stabilization.

The specimens were produced with dimensions of 40×40×100 mm. The individual results were compared with a reference sample.

3. Experimental setup

At the Department of Physics, Faculty of Civil Engineering, TU Brno, the IS-based measurements have been implemented using following instrumentation: Agilent 33220A generator, Agilent 54645A double-channel oscilloscope, HP 82350 PCI HP-IB Interface card, and a PC. To operate the above mentioned instruments and to process the IS data acquired, a software called IS alpha has been prepared by the first author of this paper. [2,3]

In order to perform impedance analysis was necessary to place the samples between brass electrodes. The samples were tested for the frequency spectra from 40 Hz to 1 MHz. Monitored variables were: loss factor tan δ (*f*), the imaginary component impedance Im*Z* (*f*) and calculated electrical capacity *C* (*f*).

Second most important measurement was realized by using the Vector network analyzer ZNC, made by Rohde & Schwarz. By using coaxial probe of Speag Company and by using Vector network analyzer, we can measure loss factor, dielectric permittivity and conductance, with very high speed, for frequency range 30MHz – 3GHz. [7,8]

4. Results and discussion

First diagnostics were realized by using non-destructive methods. The results of electrical measurements are shown in Fig. 1. Interesting results were found for all measured samples in the spectrum of dissipation factor. The spectra show polar dielectric properties at its shape. The sample which does not contain carbon admixture has only one polarization maximum for frequency 600 Hz and tan δ = 9. The sample contained only alkali-activated slag, sand, water glass and water.

And as carbon powder was added, polarization losses fell below 5. Another addition of carbon powder significantly decreased the polarization losses in the region of 500 Hz again, but the curve in the 10^4–10^6 Hz increased. The presence of carbon powder, first decreased electrical resistance of the material, but carbon also added particles for creating a dipole elements to the sample. Particles are well-polarizable across the entire frequency spectrum.

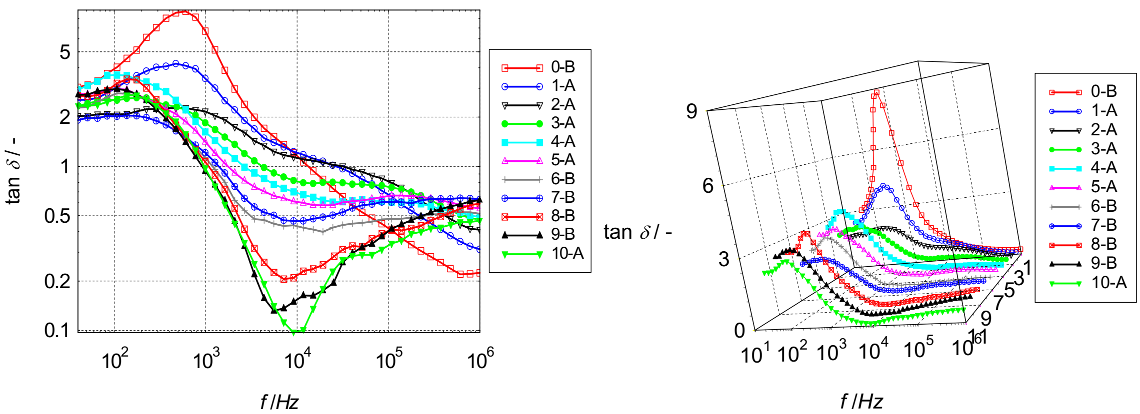

Fig. 1. (a) Spectrum of dissipation factor; (b) 3-D spectrum of dissipation factor for different mixtures.

This is also confirmed by the increase of electric capacity of the sample in the graph *C* (*f*) in Fig. 2 for all measured frequencies.

For 4% COND in the mixture there was observed again an increase of polarization loss in the low frequencies, the maximum is shifted to 100 Hz, while in the 600 Hz there is an inflection point at which the value of tan delta is lower than previously presented at an interval 600 Hz to 200 kHz. The values of dissipation factor for range 40 Hz to 600 Hz are in the range 1.5 to 4 and reach polarization maxima here. By switching axis to a logarithmic scale, Figure 1 b, for tan δ we get much more transparent view of areas of low values of tan delta. These peaks, however, "jump" with addition of water and carbon at 5% of the mixture, and 9% COND of the mixture. If maxima grow for low frequencies and by adding carbon powder too, this indicates the influence of the mixing water to the polarization losses in selected low frequencies.

From 600 Hz to 200 kHz, the values of tan delta decreased with increasing content of carbon powder to a value of tan δ = 0.1. Simultaneously water content was reduced, content of Triton increased. The amount of particles capable of polarization decreased for the frequency of 1 kHz to 100 kHz. For high frequency bands, the levels of values of dissipation factor are comparable, reaching the values around 0.5.

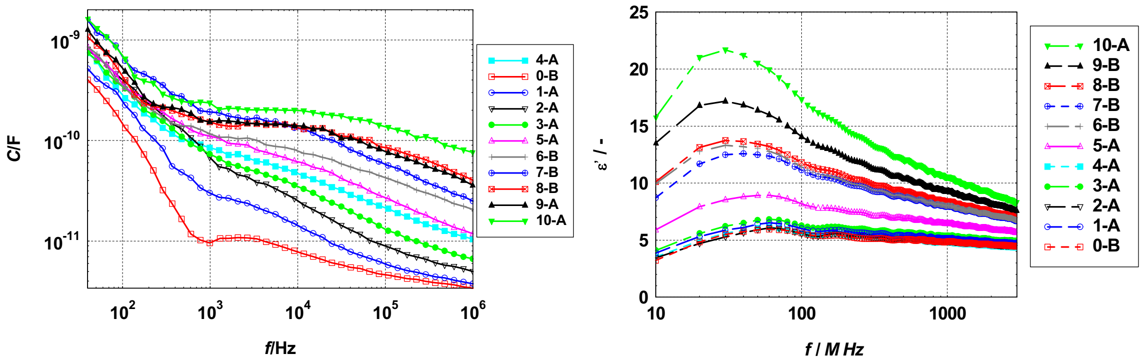

Fig. 2. (a) Spectra of electric capacity for used mixtures; (b) spectra of real part of permittivity, measured by Vector network analyzer.

The measurement by using vector analyzer showed relatively low values of the real component of permittivity of material (Fig. 2 b) for the frequency range 10 MHz to 3 GHz. Acquiring values of 5 to 22 about the first three to five values for the lowest frequency was measured significantly lower than the maximum value. This discrepancy is attributed to significant error determination of the first values for lowest frequencies; it is advisable not to take these values as relevant. The threshold of the measurability by vector analyzer was intended to determine. The presented measurement is perhaps the first diagnosis of the building materials in the world, using this top equipment.

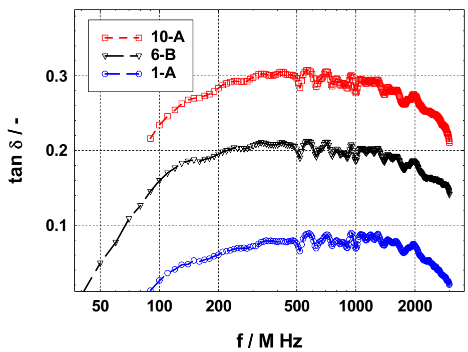

Fig. 3. Spectra of dissipation factor, measured by Vector network analyzer.

Permittivity in the area of higher frequency for the incorporation of carbon powder is increasing rapidly for concentration of 5 % and higher. With increasing frequency the values of permittivity decreases.

Low values of dissipation factor were measured using the vector analyzer. They ranged from 0.01 to 0.4, again depending on the concentration of carbon powder (Fig. 3). The curves differ not only by the level but also by the shape, but insignificantly. Measuring by vector analyzer by Speag probe are designed for gaseous and liquid environments, and measurements on solids depend greatly on the surface flatness of the material, on the closest possible of attach to the surface of the sample.

5. Conclusion

The addition of carbon powder into alkali-activated slag mortar changes the electrical properties of the samples. Carbon particles cause higher conductivity of material, also increases the electrical capacity of the sample. Observing the effect of admixture of carbon on the hardness and abrasion resistance of the samples was not the subject of this article. Carbon additives help to improve the electromagnetic shielding of construction by using waste products from the production of carbon products.

The measurability of samples using the vector analyzer was confirmed. This method does not require specially treated samples, only the smoothness of the contact surface area is necessary to be ensured.

Acknowledgements

This paper has been worked out under the project GAČR No. 16-02261S and under the project No.S-16-2967 supported by Faculty of Civil Engineering BUT.

References

[1] I. Kusak, M. Lunak, Comparison of impedance spectra of concrete recorded with utilizing carbon transition paste, Adv. Mat. Res. 897 (2014) 131–134.
[2] V. Mentlik, Dielektrické prvky a systémy, BEN – technická literatura, Praha, 2006.
[3] M. Lunak, I. Kusak, Z. Chobola, Dielectric properties of concrete specimens after heat stress, Appl. Mech. Mater. 446–447 (2014) 1389–1394.
[4] M. Cabeza, P. Merino, A. Miranda, X.R. Novoa, I. Sanchez, Impedance spectroscopy study of hardened Portland cement paste, Cement Concrete Res. 32 (2002) 881–891.
[5] T. Ficker, L. Topolar, I. Kusak, Is componential strength analysis of concrete possible?, Mag. Concrete Res. 65 (2013) 1480–1485.
[6] L. Pazdera, L. Topolar, V. Bilek, J. Smutny, I. Kusak, M. Lunak, Measuring of concrete properties during hardening, In ESA 2010. 1. CZ, Palacky University (2010) 311–318.
[7] I. Kusak, M. Lunak, P. Schauer, Tracing of concrete hydration by means of impedance spectroscopy (New tool for building elements testing), Appl. Mech. Mater. 248 (2013) 370–378.
[8] J. Ross Macdonald, W.R. Kenan, Impedance spectroscopy: emphasizing solid materials and systems, Wiley, Canada, 1987.