The Modified Cement Composite Materials for Electromagnetic Shielding and Stress Detections

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***Abstract* — This article deals with the measurement system and the use of special cement composites with carbon particulates. The type of carbon particulates consequently determines the electrical properties of cement composite material. These materials can be used for electric heating, electromagnetic shielding or stress measurement.**

Keywords-smart concrete; shielding efficiency; composite materials; carbon fibers; stress/strain detection.

I. INTRODUCTION

Nowadays, characteristics of composite materials based on cement include also other applications of cement materials which could be used, among others, for construction of self-monitoring buildings, bridges, etc. Besides, monitoring the usual properties (mechanical stability over the period of time, environmental resistance, design limits or economic profitability) is beginning to become more important and significant for construction of buildings. Requirements for construction of self-monitoring buildings are consisted of the interconnection of more different fields. In our particular case it is the question of connecting the construction and electrical engineering. At the end of the practical application self-monitoring buildings should facilitate the construction, installation or construction work.

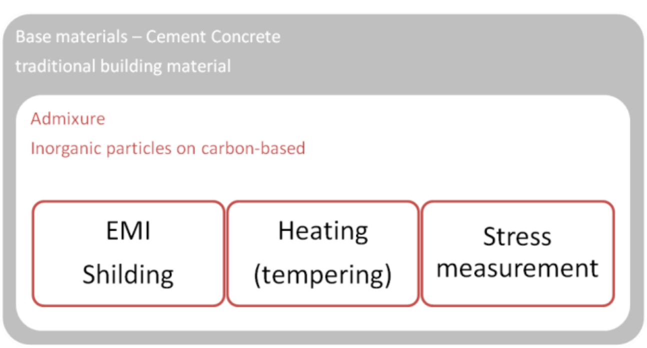

Figure 1. Three areas of application of composite materials

During the current research, which is being done, it has been found out that the composite cement materials with carbon fibers allow for monitoring transients that are generated in the material for example due to pressure, tension, temperature and humidity. This is shown in Figure 1. Electrical properties of cement composites materials can be affected by a suitably selected type and amount of carbon particles.

The purpose is to provide complete solutions, including evaluation of the implemented electronic system that allows for obtaining and transmitting information to the user. The invented self-monitoring material can be used for the implementation of an individual measuring object [1][2]. In bridge structures, it is necessary to take into consideration a possibility of the function of the autonomous operation of the system. Major part of the research is focused on solving the problems of sensing impedance of the composite material which plays an important role in issues of aging and degradation of metallic materials due to strong alkaline environments. Corrosion of electrodes can be reduced by means of suitable corrosion inhibitors. For the corrosion diagnosis the accelerated model tests are used.

For the actual application we need to know the relation between accelerated model test and the real environment.

In Section 2, there is a description of measuring electromagnetic fields shielding. In Section 3, there is a description of alternative test method for the testing of shielding effectiveness of composite shielding materials. In Section 4, there is description of theoretical aspects of mechanism of shielding. The results of alternative measurement methods are in Section 5. Next Section 6 describes response of material to stress/strain load and the last Section 7 is conclusions.

II. EMC MEASURING OF COMPOSITE MATERIALS

Measuring the effectiveness of electromagnetic fields shielding is usually done in an electromagnetic chamber. The measurements are used for transmitting and receiving antennas, test and signal generator. To receive the test signal, electromagnetic compatibility (EMC) receiver or

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spectrum analyzer are normally used. Measurements are generally usually carried out the way that the receiver, the receiving antenna and the necessary cables are placed inside the chamber or inside the test field. Transmitter (signal generator) and the broadcast antennas are located on the outer side of the tested object. The locations of the antennas depend on the EMC chamber or a box. The accuracy of the measurement depends on the correct location and position of the antennas [3][4].

The problem could appear when it is necessary to measure the shielding effectiveness of the material or the chamber or the box from which they are constructed. Especially in the development stage and in order to provide accurate measurements it is not possible to construct the whole chambers or boxes which are too big. This solution is expensive and also time consuming.

Similar problem appears when it is necessary to know the shielding efficiency of the construction materials such as bricks, plasterboard, concrete, etc. These materials could also be called, especially during their development stage, composite materials.

The main problems during the construction of chambers or boxes are caused by using the types of materials which are mentioned above. The chamber or box doors have usually the main influence on the whole shielding, in the other words, the doors always represent the weakest part of these chambers. But the construction of the doors, e.g., made from the concrete, is really complicated, almost impossible [7].

III. COAXIAL FLANGE

Materials for EMI shielding are different from those of magnetic shielding. EMI shielding is a rapidly growing application of carbon materials, especially of short carbon fibers. This review addresses measurement methods from carbon fibers materials usable for EMI shielding, including non-structural and structural composites, colloidal graphite, as well as EMI gasket materials.

The alternative test method for the testing of shielding effectiveness of shielding materials is often stated in literature [3]. The presented coaxial test apparatus is suitable for thin materials like plastic or metallic board, fabric material, etc. This setup is not suitable for the construction materials (concrete, bricks, etc.) because it is very complicated to produce the thin concrete board with the maximal height thickness of around 1 mm. The modified test setup was produced, after analyses of commonly available measurement solutions and setups. Our flange was mainly designed for frequency range from 9 kHz up to 1 GHz. The shape and dimensions of the flange were calculated for the 50 Ω input and output impedances [5].

The design of the flange was done according to the basic mathematical relations [5]

$$Z_M = \frac{60}{\sqrt{\varepsilon_r}} \ln \frac{a_2}{a_1}, \qquad (1)$$

where

Z_M is the characteristic impedance of the measurement system (50 Ω);
ε_r is the relative permittivity (in this case is equal 1, air);
a_2, a_1 are the radius of the coaxial line (flange).

The transition from the N-type connector to the opposite end of the flange has the linear shape for both central and external parts. This shape was chosen for the better fabrication. The linear shape could be optimized for the better impedance which especially should be suitable for frequencies over the 1 GHz. The central flange conductor is fabricated from the brass. The rest of the flange is made from the aluminum alloy. The flange was tightened by the torque wrench after the inserting the test composite and it was always tightened by the same value of torque. This setup increases the accuracy of each measurement and also increases the repeatability during the several measurements. The detailed description of the measurement chamber is stated in literature [7].

The measured scattering parameters of the flange itself are given in Figure 2. The S11 and S22 are in the whole range of interest under the -15 dB which refers to the good matching of the both test ports with the measuring system. The insertion losses in both directions (S21 and S12) are in the measuring frequency range less than 1 dB. This data refers to the accurate design of the whole flange. The flange itself will have the insignificant influence on the total dynamic range of the whole measurement setup. The dynamic range will be mainly affected by the used measuring devices (generator and spectral analyzer).

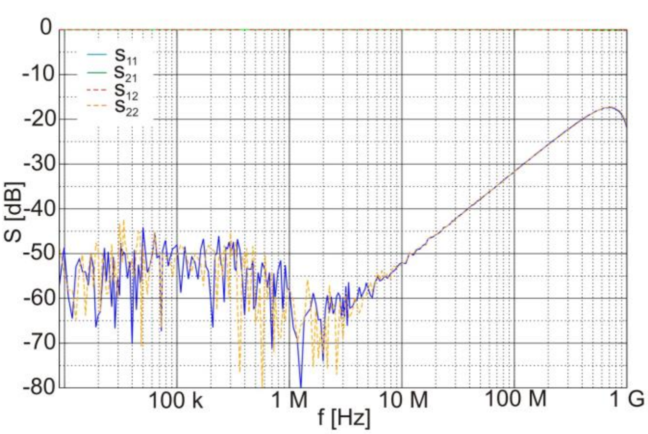

Figure 2. Measured scattering parameters of the realised coaxial flange

IV. MECHANISM OF SHIELDING

The primary mechanism of EMI shielding is usually reflection. For reflection of the radiation by the shield, the shield must have mobile charge carriers (electrons or holes) which interact with the electromagnetic fields in the radiation. As a result, the shield tends to be electrically conducting, although a high conductivity is not required. For example, a volume resistivity of the order of 1 [Ωcm] is typically sufficient. However, electrical conductivity is not the scientific criterion for shielding, as conduction requires connectivity in the conduction path (percolation in case of a composite material containing a conductive filler), whereas shielding does not. Although shielding does not require connectivity, it is enhanced by connectivity. Metals are so far the most common materials for EMI shielding. They operate mainly by means of reflection due to the free electrons in them. Metal sheets are bulky, so metal coatings made by electroplating, electroless plating or vacuum deposition are commonly used for shielding. The coating may be on bulk materials, fibers or particles. Coatings tend to suffer from their poor wear or scratch resistance [6].

Absorption is usually a secondary mechanism of EMI shielding. For significant absorption of the radiation by the shield, the shield should have electric and/or magnetic dipoles which interact with the electromagnetic fields in the radiation. The electric dipoles may be provided by $BaTiO_3$ or other materials having a high value of dielectric constant. The magnetic dipoles may be provided by Fe_3O_4 or other materials having a high value of the magnetic permeability, which may be enhanced by reducing the number of magnetic domain walls through the use of a multilayer of magnetic films. The absorption loss is a function of the product $\sigma_r\mu_r$, whereas the reflection loss is a function of the ratio σ_r/μ_r, where σ_r is the electrical conductivity relative to copper and μ_r is the relative magnetic permeability. Silver, copper, gold and aluminum are excellent materials for reflection, due to their high conductivity. Superpermalloy and mumetal are excellent for absorption, due to their high magnetic permeability. The reflection loss decreases with increasing frequency, whereas the absorption loss increases with increasing frequency [6].

V. EMI RESULTS

The measured scattering parameters refer to the accurate design of the coaxial flange. The next problem will appear with the prefabrication of the concrete ring as the test sample. This ring has to be produced with the high accuracy of its dimension. The example of measured shielding efficiency of the composite concrete material is depicted in the Figure 4. There is also shown the data which was measured with the brass disc. The shielding efficiency of the brass disc is the 115 dB at kHz range and around 70 dB at the GHz range. The shielding efficiency of the composite concrete material is only several dB in the range from 100 MHz up to 1 GHz. So low shielding efficiency of the concrete material is mainly caused by this small thickness of the material (only 8 mm). Figure 3 Measured scattering parameters of the realized coaxial flange.

Due to the skin effect, the composite material having conductive filler with a small unit size of the filler is more effective than one having conductive filler with a large unit size of the filler. For effective use of the entire cross-section of a filler unit for shielding, the unit size of the filler should be the same or smaller than the skin depth. Therefore, the filler of unit size 1 µm or less is typically preferred, though such a small unit size is not commonly available for most fillers and the dispersion of the filler is more difficult when the filler unit size decreases. Figure 4 shows the observed parameters for different types of carbon materials.

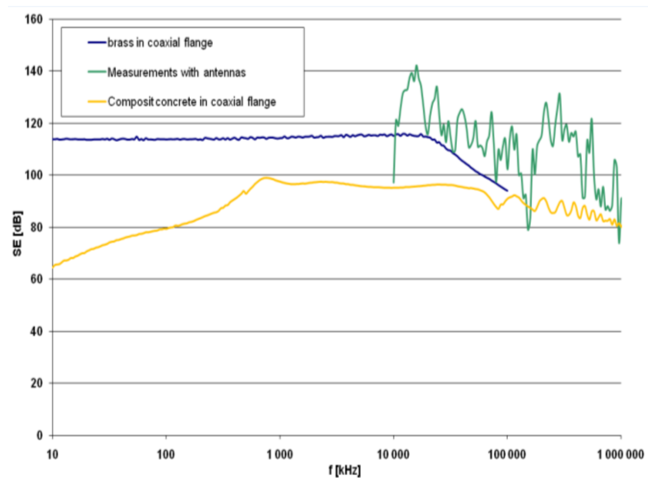

Figure 3. Shielding efficiency of the brass calibration test disc and the composite concrete test sample.

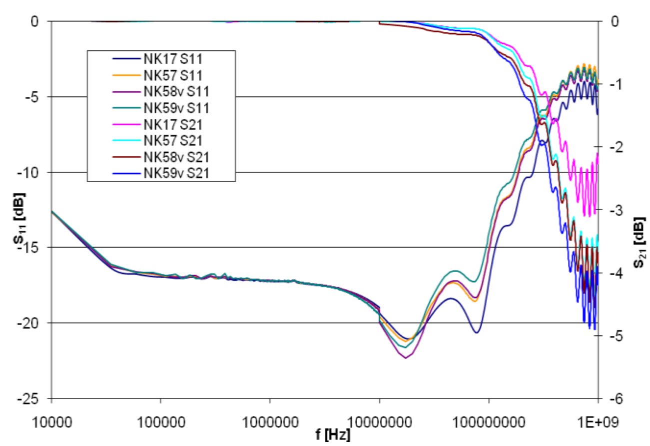

Figure 4. Shielding efficiency of the brass calibration test disc and the composite concrete test sample.

VI. STRESS/ STRAIN MEASUREMENT

Another usage of smart concrete is used for sensing the load of concrete elements and structures mainly for measurements which use strain gauges. A strain gauge is a device used to measure strain on the surface part, by means of mechanical stress (tension, compression, etc). In fact, the strain gauge measures the relative deformation. Mechanical stress cannot be measured directly, and thus converted from the measured deformation. To calculate the necessary knowledge of the modulus of elasticity of material under consideration.

Composite material with carbon particles is sensitive to load changes [8]. This sensitivity is manifested by a rapid change of the measured impedance. Measurement was carried out in static mode. Gradually the load was adjusted in range from 0 kN to 1500 kN, after reaching a maximum, the sample was gradually relieved to the minimum load of 200 kN. The characteristic diagram of impedance response for smart concrete measured to stress load are given in Figure 5. Strain properties of the composite can be evaluated by changing impedance. The impedance changing sensitivity regarding the deformation can be widely affected by a proper choice of concrete admixtures [8]. Generally, in all types of carbon admixtures, the impedance of component is affected by the deformation and can be used to detect the changes. For impedance measuring we used an excitation frequency at 1 KHz, and an excitation voltage of 1 V (peak-peak) were experimentally set. Appropriately selected admixture has an effect on the relative size of the impedance changes depending on the pressure. The voltage level of the measuring voltage depends on used metal electrodes. For measuring impedance we used copper electrodes. These electrodes have a high resistance to corrosion in an alkaline environment..

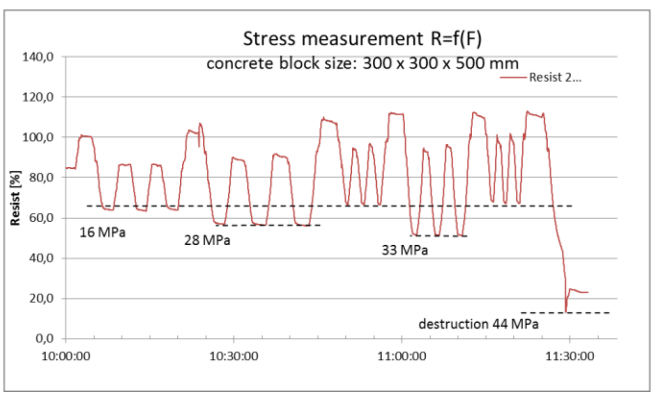

Figure 5. Concrete block - stress measurement

VII. CONCLUSIONS

Composite materials with carbon fibers were produce. Cement composite materials with admixture of carbon particulates, can be really used for electromagnetic shielding or stress sensing. The shielding efficiency of material is composed from several parts. The reflection loss, absorption loss and multiple path reflection losses are the main three parts of the whole electromagnetic shielding. For the accurate classification of the shielding efficiency of composite concrete material it will be necessary to measure each part of the whole electromagnetic shielding effectiveness. This measurement could be done by the vector network analyzer. The dependency of the thickness of the material and shielding efficiency could be determined in the harmony with measured data. The future work on EMI shielding will be focused on these problems and also on the compound of the composite concrete materials.

Some of these materials are stress sensitive and we were measured them under cyclic press loading in range from 0 kN to 1500 kN, after reaching a maximum, the sample was gradually relieved to the minimum load of 200 kN. The future work on stress measurement will be focus to increase the sensitivity of smart concrete materials.

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