Possibilities to improve electromagnetic shielding of plaster composites adding carbon fibers

A Samková¹, P Kulhavý¹ and M Pechočiaková¹
¹Technical university of Liberec, Studentská 1402/2 46117 Liberec, Czech Republic
Email: alzbeta.samkova@tul.cz

Abstract. This paper studies size of electromagnetic shielding in plaster composites, using different volume fractions of carbon fibers. Conventional types of plaster, which are normally used in construction (i.e. cement, lime, gypsum and lime cement) were the main parts of the created composites. The carbon microfibers with a length of 8 mm were added as reinforcing and simultaneously shielding element into plaster samples. The tested samples were created at three different volume fractions of the fibres and also into the base plaster for possibilities of their comparison. The results of carried measurement show that the electromagnetic shielding in the plaster composite grows with increasing fiber content in the tested ratio almost linearly.

1. Introduction
Currently, there is a continual development and expansion of electronics, which also brings a negative impact in terms of increases in man-made sources of electromagnetic fields. Some of electromagnetic phenomenon may adversely affect living or nonliving matter or cause deterioration of the operating device, that could be described as electromagnetic interference. Artificially created electromagnetic fields (known as electrosmog) have a negative biological impact not only on a human body, but also on each of the conductive body [1].

Commonly used electric and electronic devices are capable of emitting electromagnetic waves with frequencies that pose a potential risk to human organism [2, 3]. Receiving electromagnetic radiation may lead to electromagnetic interference (EMI). Most often the EMI occurring in the radio frequency EM spectrum from 104 to 1012 Hz. This energy emit a fluorescent lamp, radio transmitters, lightning, power lines and other sources. Modern satellite and wireless communications use the microwave region defined from 1 GHz to 40 GHz [4]. The materials used for forming electromagnetic shielding are characterized by a particularly high conductivity and high permeability.

Recently, there is tendency to eliminate the harmful effects of radiation on workstations by direct protection of the worker using curtains, screens etc. For this purpose fabric of electrically conductive yarns [5, 6], metallized yarns or full metallised fabric [2, 7] have been developed. An alternative to these methods are shielding by conductive polymers. Unlike metallic shielding materials, conductive polymers may not only reflect, but also absorb electromagnetic radiation at microwave frequency [8, 9].

Probably the most important material in the building industry is a cement. Cement matrix itself exhibits poor shielding effects. For this reason, through a research or experiments is lot of efforts to improve the shielding effect of cement composites. Wang et al [10] investigated the ability of cement nanocomposites absorb electromagnetic waves. Khushnood et al. focused on cost-effective
material and to achieve better properties EMS used agricultural residues in the form of peanuts and hazelnuts shells. These wastes were pyrolysed at 850 °C. The resulting plaster composites showed significant improvement in shielding against electromagnetic interference [11].

2. Material and preparation
As has been already mentioned, 4 kinds of plasters (cement, lime, gypsum and lime cement) have been used. The carbon fibers with a declared mean diameter 1.76 µm were selected to achieve the shielding effect. For plaster composites with micro fiber reinforcement to compute the critical fiber length:

\[ l_c = \frac{R_{mV} \times d}{2\tau_m} \]  \hspace{1cm} (1)

where \( l_c \) [mm] is the critical fiber length, \( R_{mV} \) [MPa] fiber strength, \( d \) [mm] is the diameter of the fibers and \( \tau_m \) [MPa] strength of the interface between the fibers and the matrix in shear.

The critical fiber length is the minimum length of fiber which is still capable of transmitting tension. This length can be achieved only with difficulty, due to the very small size. The effective length of the fibers was determined according to W. D. Callister [12] by formula (2):

\[ l = 15 \times l_c \]  \hspace{1cm} (2)

These formulas are for composites with polymeric matrix. Because the different matrix was used in the experiment, it was necessary to recalculate the effective length by using correlation factor. The short-fiber composites are characterized by the aspect ratio \( \alpha \) (3). It is the ratio between the length of the fiber and its diameter.

\[ \alpha = \frac{l}{d} \]  \hspace{1cm} (3)

The final length of the carbon fibers is 8 mm.

The content of the fibrous reinforcement in concrete materials is usually 6%. Blending the plaster and fibers with thus high content causing problems in their bonding. For this reason the content of the fibrous reinforcement has been set to 1%, 2% and 3%. The calculation (5) of the mixing ratio [13] is based on the percentage of the components in the composite and their densities:

\[ w_i = \frac{V_i \times \rho_i}{\sum V_i \rho_i} \]  \hspace{1cm} (5)

where \( w_i \) [%] is the mass fraction of the i-th component, \( V_i \) [%] the volume fraction of the i-th component and \( \rho_i \) [kg/m³] is the density of the i-th component.
3. Experiment and testing
Electromagnetic shielding effectiveness of the individual samples was measured according to ASTM D 4935-10 [14]. This standard is intended for evaluating the effectiveness of shielding materials using plane waves falling on a shielding bulkhead near the zone of electromagnetic field. All specimens were tested using a shielded waveguide (modification methods shielded mailbox) Fig. 2. Measuring devices containing a sample holder coaxial shape. Input and output of the holder has been connected to the peripheral analyzer. For generating and receiving the electromagnetic signal used network analyzer [1].

Performed tests ranged from 30 to 3000 MHz, which is the most common band used for public communication and data transfer. For each content of fibrous reinforcement was measured five samples from each group i.e. free, 1, 2.3%. In order to establish a clear conclusion on the parameter of attenuation in the GSM bands, 3G, LTE and WiFi networks IEEE 802.11 hypothesis was formulated by their average value and statistically validated.
For the analysis of the shielding effectiveness of test samples can be used formula expresses absorption loss $A_{\text{sheet}}$ [dB] and reflection loss $R_{\text{sheet}}$ [dB] that can be written:

$$A_{\text{sheet}} = 0.0848 \times t \sqrt{\frac{K}{K_c}} f$$  \hspace{1cm} (6)

$$R_{\text{sheet}} = C + 10 \log \left( \frac{K}{K_c} f \right)$$  \hspace{1cm} (7)

where the constant $C$ is listed in Tab. 1 for plane waves, electric fields and magnetic fields, respectively. $K$ [S/cm] is the volume conductivity and $K_c$ [S/cm] is cooper conductivity, $f$ [MHz] is the frequency and $t$ [m] is thickness of the shield. [15]

| Type of field      | C    |
|--------------------|------|
| Electric field     | 322  |
| Plane wave         | 168  |
| Magnetic field     | 14.6 |

**Table 1** Constants used in Equation (6, 7)

4. Result and discussion
The electromagnetic shielding effect was measured for three sets of samples for 4 different kinds of plaster with the various fiber weight ratio. The dependence of inner damping SE (dB) on frequency was monitored for all of the investigated samples. In Fig. 3 the results of electromagnetic shielding for reinforced and also the pure plaster materials could be seen. The measured dependencies of shielding show that the effectiveness of damping increases with rising content of the fibrous in the plaster. This trend is most noticeable with the lime plaster.

**Figure 3** Results electromagnetic shielding
5. Conclusion
Based on the measured data is possible to declare that with increasing content of fiber grows the shielding ability in the plaster composites. Despite this fact, is the content of fibrous reinforcement more than 3% less suitable, because of arising negative impact to the mechanical properties, as could be read in the author previous articles. So probably the content 1 - 2 %, which according to Tab. 2 means shielding group: Good - Very good, is the most suitable.

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