EFFECT OF DIFFERENT NANOMATERIAL ADDITIONS IN CLAY-BASED COMPOSITES

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ABSTRACT
In this study, electromagnetic (EM) radiation shielding of a clay composite with three different admixtures was tested. Because of the rapid development of new modern technologies, human exposure to non-ionizing EM radiation has grown exponentially. This has aroused the interest of scientists to answer the question of how long-term exposure to EM radiation is harmful to human health. Due to potential risks to human health and an increasing number of studies that have concluded that long-term EM radiation can be harmful to health, the WHO has classified the radiofrequency band (from 300 kHz to 300 GHz) as a potential cause of cancerous diseases. The frequency span 1.5–6 GHz was tested. Admixtures used as a partial replacement in mass percentage are fly ash, titanium dioxide and zinc ferrite. The percentage replacement was 5%. The results showed the lowest transmission in specimens with titanium dioxide addition. The lowest transmission in regards to the reference sample was about −10 dB. This research was done with the aim of production of load-bearing bricks with high protection against EM radiation for the construction of healthy buildings.
Keywords: clay, fly ash, titanium dioxide, zinc ferrite, electromagnetic radiation shielding.

1 INTRODUCTION

Electromagnetic (EM) radiation can be defined as the transmission of energy that travels throughout the medium in the shape of electric and magnetic fields. EM radiation travels at the speed of light. Probably the "most popular" type of EM radiation is light. Depending on the frequency, electromagnetic radiation includes radio waves, microwaves, infrared, light, ultraviolet, X-rays and gamma rays. All these waves belong to the electromagnetic spectrum. As the frequency of a wave is higher, it transmits higher energy. At one point, that energy becomes so high, it can ionise atoms by detaching electrons from them. This type of radiation is called ionising radiation. Exposure to such types of radiation is not frequent. People are often exposed to low intensity ionising radiation in hospitals due to examinations. However, exposure to non-ionising radiation is much more common. People are every day surrounded with a mixture of electric and magnetic fields. Non-ionising radiation comes from various devices such as mobile telephony systems (3G, 4G, 5G), wi-fi, wireless devices, radars, home appliances, among others. Each of these sources operates at different frequencies. Short time exposure to higher amounts of non-ionising radiation can cause decreased concentration, sleep problems, mental disorders and stress. While scientists' opinions on short-term exposure to non-ionising radiation are similar, opinions on the consequences of long-term exposure to non-ionising radiation are divided. One part of scientists believe that long-term exposure does not have a negative impact on human health, while other part of scientists believe long-term exposure to non-ionising radiation may result in an increased risk of developing cancer. Khurana et al. [1] compared the risk of developing neurobehavioral symptoms or cancer in populations living at distances < 500 m from base stations in available studies. Authors reported an increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at distances < 500 m from base stations found in 80% of the available studies. Calvente et al. [2] published a comprehensive review of the literature on

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the subject, studying research from 1979 to 2008. The results of the literature review showed that most research in this period found an association between childhood leukaemia and exposure to electromagnetic radiation, especially when exposed to very low frequencies. Because of these growing concerns, the IARC (International Agency for Research on Cancer) 2001 classified very low frequencies as potentially carcinogenic [3]. Ten years later, in 2011, the same agency added radio frequencies (from 300 kHz to 300 GHz) to the group of potentially carcinogenic samples [4]. The IARC divides potential cancer agents into three groups: (1) they are carcinogenic; (2) they are probably carcinogenic; and (3) potentially carcinogenic. Due to insufficient research, but growing concerns, exposure to non-ionising radiation belongs to the "weakest", the third category. There are three most common ways of reducing our exposure to non-ionising radiation: First, limiting time spent in rooms with high levels of electromagnetic radiation, second, gaining distance – just as the heat from a fire decreases as a person moves away, the radiation dose decreases dramatically as you increase the distance from the source and third, the use of walls or barriers that have the ability to protect against EM radiation which can significantly reduce the spread and exposure to electromagnetic radiation. The first two ways cannot be considered as long-term solution, while the use of barriers or walls in rooms can significantly reduce long-term exposure to EM radiation. Materials such as clay bricks cannot be barriers by itself because of the high electrical resistivity that clay has (around 106 Ωm) [5]. This study explored way of improving EM shielding potential of clay composites by adding different additives which have been shown to be effective in concrete. Analysed additives are: fly ash, zinc ferrite ($ZnFe_2O_4$) and titanium dioxide (TiO_2) [6]. The additives percentage in clay composite was 5% by mass. The study analysed the frequencies to which people are most often exposed including: 4G bands (1.80–1.88 GHz, 2.11–2.17 GHz, 2.62–2.69 GHz), 5G band (3.45–3.80 GHz), wi-fi (2.4 GHz) and navigational radar (2.9–3.1 GHz).

2 SPECIMEN PREPARATION

Clay was supplied from a local brick factory, after which it was dried and reduced to the desired granulation. Clay and additives were mixed in a dry state, after which water was applied to achieve desired moisture (around 22 wt.%). For each additive, three specimens were made to achieve more reliable results. Specimens were circular with 15 cm diameter and 2 cm thickness. Clay specimens were moulded and compacted with the Proctor device. After that, specimens were dried at adequate room humidity to avoid any cracking. Dried specimens were exposed to firing at a temperature of 850°C. Fig. 1 shows the heating program.

3 EXPERIMENT SETUP

Transmission measurement was achieved using Anritsu ms2038c Handheld Vector Network Analyser and Spectrum Analyser. The analysed frequency was 1.5–6.0 GHz, where scattering parameters (S-parameters) were measured for providing transmission, reflection and absorption values. As mentioned before, for each additive, three specimens were made, after which the mean value was taken and compared to the other values. There are various standard test methods for measuring shielding efficiency. They can be classified into small-sample testing and large-sample testing. ASTM D4935-18 can be considered representative for small-sample testing. The problem with this method is the specimen's small thickness (around 25 μm) that is not possible to fabricate [7]. On the other hand, standards like IEEE-STD-299 that is a representative large-sample test, prescribe a higher testing area, and the specimen dimensions need to be 2.0 m^2 × 2.0 m^2. For these reasons, an experiment was based

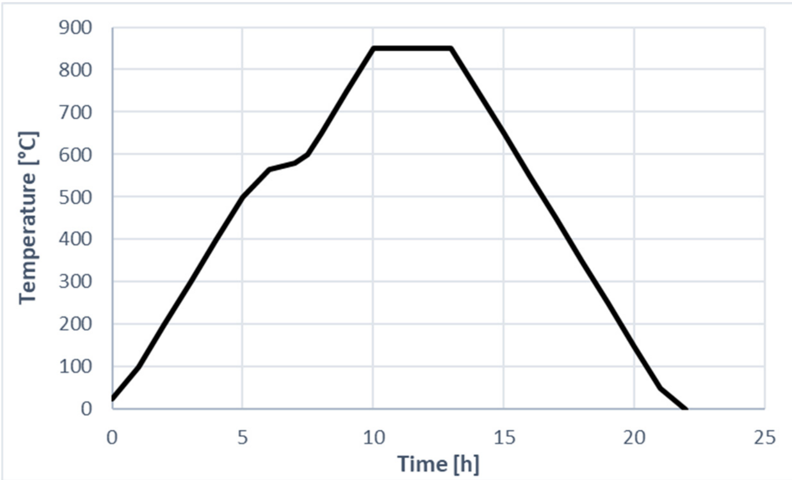

Figure 1: Firing process.

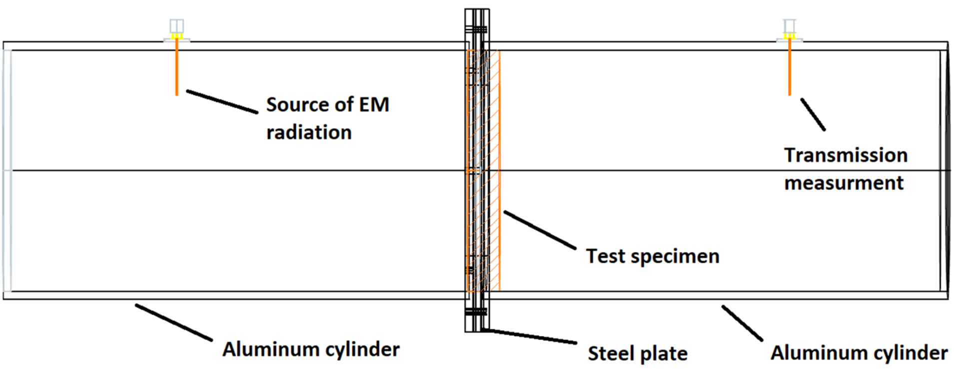

Figure 2: Experiment setup.

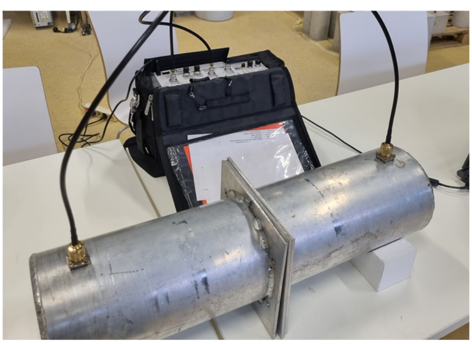

Figure 3: Measuring process.

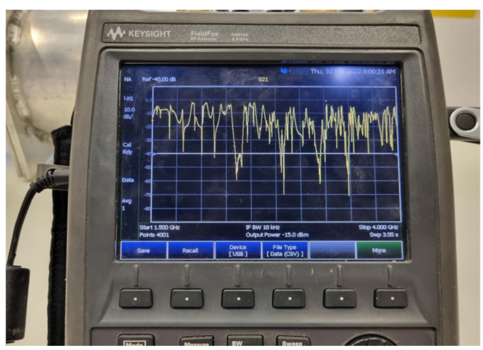

Figure 4: Transmission measurement.

on an enlarged ASTM D4935-19 test. The measurement setup consisted of two aluminium cylinders between which a specimen holder was placed (Fig. 2). To avoid any space between specimen and specimen holder, aluminium foil was placed. Two cylinders and the specimen holder were connected with screws.

4 RESULTS

Transmission, absorption and reflection results were measured for a frequency span 1.5–6.0 GHz (Fig. 4). At these frequencies, most of the fixed radiation sources are. Special attention was given to frequencies at which mobile telephony systems operate, wi-fi networks and navigational radar: 4G bands (1.80–1.88 GHz, 2.11–2.17 GHz, 2.62–2.69 GHz), 5G band (3.45–3.80 GHz), wi-fi (2.4 GHz) and navigational radar (2.9–3.1 GHz). Values are presented using S-parameters. S_{21} parameter displays the transmission. The transmission shows the difference in the level of electromagnetic radiation before and after passing through the sample. The lower the values of the curves in the diagrams then the lower the transmission is. Measurement results are shown in Fig. 5.

From Fig. 5(a), (b) and (e), it can be concluded that adding zinc ferrite, titanium dioxide or fly ash to clay did not reduce transmission in first two 4G frequency spans or wi-fi frequencies. Although first two frequency spans at which 4G operate did not show any transmission reduction, third frequency span (2.62–2.69 GHz) has shown significant transmission reduction in specimens where titanium dioxide was used. Transmission reduction was around −10 dB. In 5G band (3.45–5.80 GHz) specimens with titanium dioxide again have proven to be most efficient for transmission reduction. Maximum reduction was −6.7 dB at 3.6 GHz. Highest reduction in transmission at frequencies where navigational radar operates have again been shown in specimens with titanium dioxide. Transmission reduction was reported throughout the entire range from 2.9–3.1 GHz. Maximum reduction was measured at 3 GHz and it was 8.3 dB. Specimens with fly ash or zinc ferrite did not show any significant reduction in any of the analyzed frequency ranges.

5 CONCLUSION

Due to growing concerns about the potentially harmful long-term effects of non-ionizing radiation, more and more research is investigating how to reduce our exposure most effectively to radiation. This study analyzed the electromagnetic shielding capabilities of the clay composites for the frequency range of 1.5–6 GHz. Admixtures that were used as partial clay replacement were: fly ash, titanium dioxide and zinc ferrite. Clay composite specimens containing fly ash or zinc ferrite did not show significant change relative to the reference sample. The assumption is that fly ash does not have a sufficient amount of hematite in its chemical composition (most often up to 10%), which increase conductivity of the material and lead to reduced transmission of EM radiation. Despite the fact that zinc ferrite has good magnetic properties, the results showed minimal improvements in electromagnetic shielding (only a few dB). The results are in line with those from other literature, where a significant improvement in protection was shown only when a 50% replacement of zinc ferrite was used in the mortar. Clay composites with titanium dioxide have shown highest potential for electromagnetic shielding. The highest transmission reduction measured was around 9 dB at 4G frequency span 2.62–2.69 GHz. These results show the possibility and potential of using titanium dioxide in real clay bricks that could provide significant protection against electromagnetic radiation.

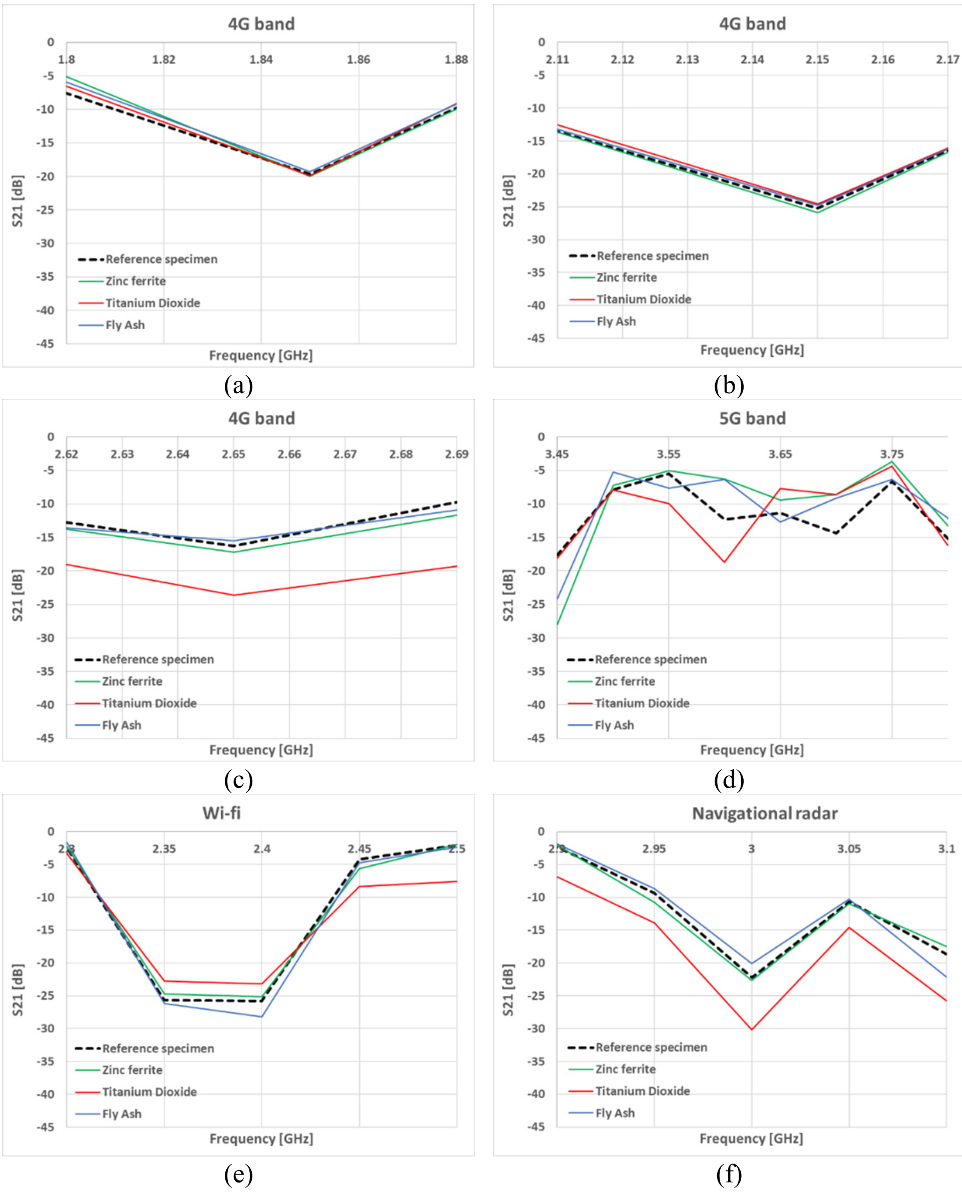

Figure 5: Measured S_{21} parameter of clay composite samples for (a) 4G, 1.80–1.88 GHz; (b) 4G, 2.11–2.17 GHz; (c) 4G, 2.62–2.69 GHz; (d) 5G, 3.45–3.80 GHz; (e) Wi-fi, 2.4 GHz; and (f) Navigational radar, 2.9–3.1 GHz.

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