UDC 666.651 doi: 10.15407/hftp14.02.249

V.I. Hryhoruk [1], V.V. Oliynyk [1], V.V. Zagorodniy [1], G.V. Lisachuk [2], R.V. Kryvobok [2], V.V. Voloshchuk [2], M.S. Maystat [2], O.M. Lapuzina [2]

STUDY OF THE ELECTRODYNAMIC PROPERTIES OF COMPOSITE CERAMICS

[1] Taras Shevchenko National University of Kyiv
64 Volodymyrska Str., Kyiv, 01033, Ukraine, E-mail: info@knu.ua
[2] National Technical University "Kharkiv Polytechnic Institute"
2 Kyrpychova Str., Kharkiv, 61002, Ukraine, E-mail: omsroot@kpi.kharkov.ua

Nowadays, people are constantly under the influence of electromagnetic radiation, which can cause health deterioration. The creation of ceramic materials that protect biological and technical objects from the negative effects of electromagnetic radiation is relevant for Ukraine and the world. The purpose of the study is to create composite ceramics with the addition of graphite and conduct experimental studies of the electrophysical properties of such material samples in the frequency range of 26–37.5 GHz. The results of experimental studies of the developed ceramics based on facing tiles with an electrically conductive additive of 10, 20, and 30 % wt. of graphite. To determine the parameters of the interaction of electromagnetic radiation with the samples, the modernized standard equipment – P2-65 microwave standing wave coefficient and attenuation meter, was used. The phase composition of the material was determined using the method of X-ray phase analysis using a DRON-3M diffractometer with CuK_{α} radiation with a nickel filter. The developed composite ceramic materials meet the basic requirements for the operation of similar materials and can be used to weaken the high-frequency electromagnetic field inside premises located in the areas of radio radiation action, and for environmental purposes to reduce the intensity of the electromagnetic field outside the premises where sources of radio radiation are present. Thus, the developed composite ceramics have characteristics that allow them to be used in construction and in electronic devices for the purpose of effective shielding of harmful radio radiation, and the developed ceramics, according to the classification, can be classified as radio-absorbing.

***Keywords**: electromagnetic radiation, radio-absorbing ceramics, conductive additives, electrophysical properties, transmission coefficient, reflection coefficient, X-ray phase analysis*

INTRODUCTION

At work and at home, a person is exposed to electromagnetic radiation from computer, office and household appliances; analog and cellular communication; medical equipment; broadcast radio; navigation systems and many other sources [1]. A higher than permissible intensity of electromagnetic radiation can lead to increased fatigue, central nervous system disorder, clouding of the lens of the eye, *etc*. [2–4]. Extraneous radiation adversely affects the technical condition of electronic devices up to their failure, which is extremely dangerous under the conditions of the spread of automated control systems for technological processes [5, 6].

Traditionally, metals and their alloys [7] and ferrites [8, 9] are used to protect against electromagnetic radiation, the use of which in its pure form is impractical for both economic and technological reasons. It is more rational to use the appropriate materials in the form of additives during the production of protective materials of the composite type, namely, the introduction of electrically conductive impurities into the dielectric matrix. Due to this, there is a decrease in specific volume resistance and an increase in the dielectric constant of ceramic materials. The main disadvantages of the majority of used composite materials are low strength, flammability, toxicity, associated with the use of various organic substances as matrices (resins, rubbers, paints, varnishes, *etc*.) [10]. These disadvantages can be eliminated if ceramics are used as a matrix.

Metals and their alloys, graphite and some other substances are mainly used as conductive additives [11]. Common additives used for electromagnetic protection materials are mainly unstable during heat treatment (burn out, react with the formation of new products that have high resistivity values), which is a negative factor for creating protective composite ceramic materials.

It is known from the literature [11–18] that graphite oxidizes at low temperatures. But since during the production of shaped ceramics, a high-speed firing mode is used, it can be expected that not all graphite will oxidize with the formation of new compounds. Therefore, contrary to the requirements for conductive additives, graphite was used as a filler.

The creation of ceramics that protect biological and technical objects from the negative effects of electromagnetic radiation is relevant for Ukraine and entire world.

The purpose of our study is to create composite ceramics with the addition of graphite and conduct experimental studies of electrophysical properties in the frequency range of 26–37.5 GHz.

THEORETICAL PART

During the passage of a wave through a material, the interaction of radiation with it is determined by the amount of attenuation S_{21}, reflection S_{11} and absorption S_A [19]:

$$S_{21} = S_{11} + S_A + S_{MR},$$

where S_{MR} – is the indicator of multiple internal reflection.

The amount of reflection S_{11}, dB, is equal to:

$$S_{11}=20lg\left|\frac{VSWR-1}{VSWR+1}\right|,$$

where $VSWR$ – is the standing wave factor by voltage.

The amount of absorption S_A, dB, is equal to:

$$S_A = 20lge^{d/\delta}, \quad \delta = (\pi f \mu \sigma)^{-1/2},$$

where d – is the thickness of the sample, f – is the frequency of radiation, μ – is the magnetic permeability of the sample, σ – is the conductivity of the sample.

Multiple internal reflection index S_{MR}:

$$S_{MR} = 20lg\left|1 - e^{-2d/\delta}\right|.$$

A small effect of multiple reflection in composites with high conductivity filler concentrations applied is typical and may be ignored.

EXPERIMENTAL PART

The production of ceramic mass was carried out under the condition of using the lowest temperature and firing time, taking into account that the additive can oxidize, burn out or interact with the dielectric matrix. In this study, ceramic mass for the production of facing tiles was used.

A promising direction of research is the creation of composite materials based on a dielectric matrix and a conductive additive (coke pitch electrode, technical carbon, carbon black, graphite, iron carbonyl, silicon carbide, silicon, aluminum, iron, copper, nickel, iron(III) oxide, copper(II) oxide) [20–22].

Taking into account the requirements [22–27] put forward for electrically conductive additives for the creation of electrically conductive ceramic composite materials, graphite (TKLR – $7.5\cdot10^{-6}$ deg^{-1}, ρv – $8\cdot10^{-6}$Ohm·m, T_m– 3850 °C) was chosen from the set of traditionally used additives for composite materials of electromagnetic protection.

Based on the need to ensure the manufacturability of the mass, the proportion of the additive was in the range from 10 to 30 mass. %. The developed composite ceramic tile consists of two layers (Fig. 1).

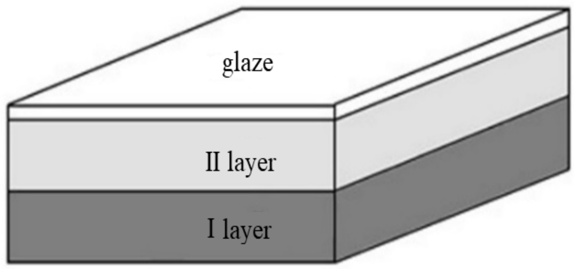


Fig. 1. Graphite-containing composite ceramic tile

Batch compositions for I and II layers for tiles are presented in Table 1. Press powder for I and II layers was obtained separately from raw materials in a given amount, which were weighed, moistened, ground in a layer mill; the slurry was dried in a drying cabinet, then crushed and passed through a sieve N 05. First, the press powder for the I layer, moistened up to 8 %, was weighed and poured into the press mold, the pressure force was 5 MPa; after that the press powder for the II layer, moistened up to 8 %, was weighed and poured into a mold for pressing, the pressure was 18–20 MPa. The obtained raw material was dried. Next, the semi-finished product was covered with glaze and placed in a drying cabinet. The finished semi-finished product was fired in a silite furnace at a firing temperature of 1.120–1.140 °C, with exposure at the maximum temperature of 20 min.

Table 1. Furnace burden components for tiles

Name of raw materials	Mass content of materials, wt. %			
	II layer	I layer		
		1	2	3
Andriivska Clay	43.00	38.70	34.40	30.10
Granite sifting	13.00	11.70	10.40	9.10
Graphite	–	10.00	20.00	30.00
Quartz sand	29.04	26.14	23.23	20.33
Crushed Chalk	8.03	7.23	6.42	5.62
Tile Remainders	6.93	6.24	5.54	4.85

Measurements of the electrodynamic characteristics of the samples – transmission and reflection coefficients – were carried out in the frequency range of 26–37.5 GHz. Standard rectangular waveguides with a cross section of 7.2×3.4 mm^2 were used. The tested samples completely covered the cross-section of the waveguide and had a thickness of 1.5 mm. To determine the parameters of the interaction of electromagnetic radiation with the samples, the modernized standard equipment–standing wave ratio meter and attenuation P2-65 with indicator Y2P-67 – was used. The transmission coefficient was determined according to the scheme shown in Fig. 2.

The attenuation coefficient S_{21} was determined according to the attenuation scale of the P2-65 ratio meter in decibels. When reorienting the directional coupler 3 by 180 degrees, the voltage standing wave coefficient – *VSWR* – was measured. According to the formula: $k_{reflection} = 20*lg((VSWR - 1)/(VSWR + 1))$, the reflection coefficient in decibels was calculated.

The phase composition of the test samples was determined using the *X*-ray phase analysis method using a DRON-3M diffractometer with CuK_α radiation and a nickel filter under standard operating conditions. To identify the phases, the American ASTM catalog was used [13].

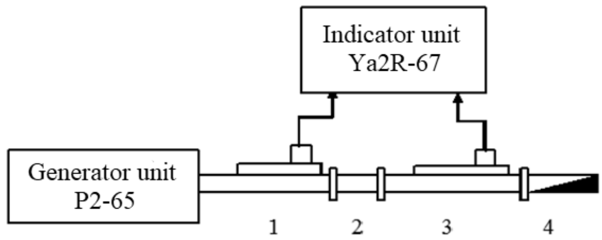


Fig. 2. Block diagram of the experimental setup for determining the attenuation coefficient S_{21}: *1*, *3* – directional splitters, *2* – waveguide with a sample, *4* – coordinated load

In Fig. 3 and Fig. 4 the spectra of the attenuation and reflection coefficients of the wave passing through composite ceramics with the addition of 10, 20, and 30 wt. % of graphite are shown. In Fig. 5 the results of *X*-ray phase analysis in the form of a line X-ray pattern for a sample with the addition of 10 % graphite in the first layer after firing are shown.

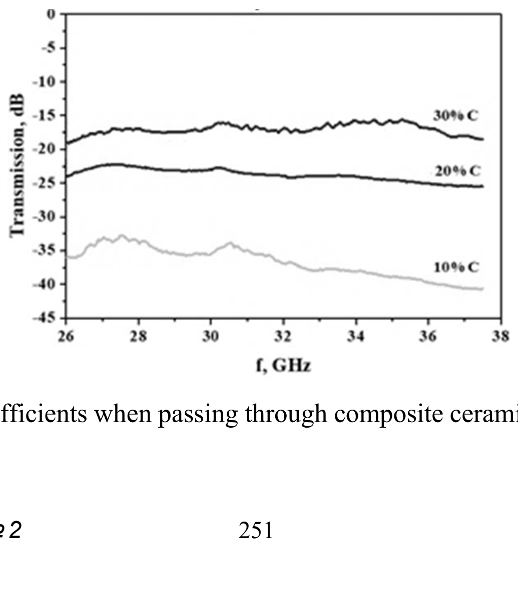


Fig. 3. Spectra of attenuation coefficients when passing through composite ceramics with the addition of 10, 20, and 30 wt. % of graphite

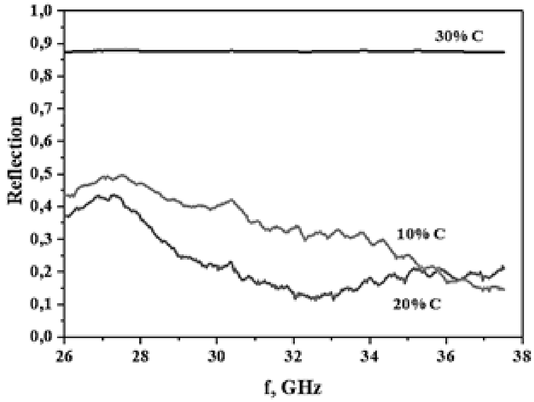
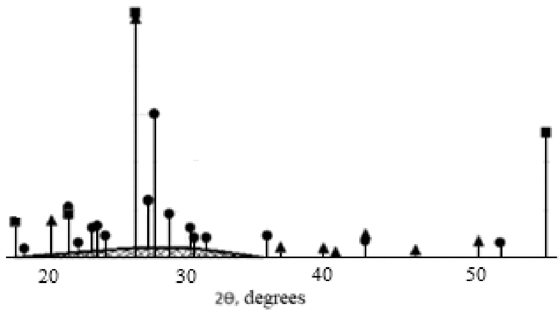


Fig. 4. Spectra of reflection coefficients when passing through composite ceramics with the addition of 10, 20, and 30 wt. % of graphite



● – plagioclase; ▲ – SiO_2 (quartz); ■ –graphite

Fig. 5. *X*-ray as a barcode of composite ceramics with 10 % graphite in the Ist layer after firing

The study of these samples showed that the addition of graphite to ceramics reduces the wave attenuation coefficient from 40 dB at 10 wt. % of graphite up to 20 dB at 30 wt. % of graphite. At the same time, a small wave reflection is observed in a part of the frequency range.

Also, the *X*-ray as a barcode showed that after firing, graphite remained in the composition of the first layer, which is an important condition for obtaining radio-absorbing ceramics according to classification-identification.

All of the above points to the prospect of using graphite-containing ceramics as a material for absorbing ultra-high-frequency radio waves.

CONCLUSIONS

The electrodynamic characteristics of electrically conductive composite ceramics with the addition of graphite in the microwave range of 26–37.5 GHz were studied. According to the results of the conducted research, the laws of the change of the attenuation coefficient were established and the attenuation of the electromagnetic wave by 20–40 dB was found dependent on the amount of graphite additive (10, 20 or 30 wt. %) in the electrically conductive ceramic tile. There is also a small reflection of the wave in the frequency range above 30 GHz, which indicates the prospect of using graphite-containing ceramics as a material for absorbing radiowaves.

The developed and manufactured composite ceramic materials meet the basic requirements for the operation of such materials and can be used to weaken the high-frequency electromagnetic field inside premises and for environmental purposes to reduce the intensity of the electromagnetic field outside the premises, in which there are sources of radio radiation.

Дослідження електродинамічних властивостей композитної кераміки

В.І. Григорук, В.В. Олійник, В.В. Загородній, Г.В. Лисачук, Р.В. Кривобок, В.В. Волощук, М.С. Майстат, О.М. Лапузіна

Київський національний університет імені Тараса Шевченка
вул. Володимирська, 64, Київ, 01033, Україна, info@knu.ua
Національний технічний університет «Харківський політехнічний інститут»
вул. Кирпичова, 2, Харків, 61002, Україна, omsroot@kpi.kharkov.ua

У наш час людина постійно перебуває під впливом електромагнітного випромінювання, яке може призвести до погіршення здоров'я. Актуальним для України та світу є створення керамічних матеріалів, які захищають біологічні та технічні об'єкти від негативної дії електромагнітного випромінювання. Метою роботи є створення композитної кераміки з додаванням графіту та проведення експериментальних досліджень електрофізичних властивостей зразків такого матеріалу в діапазоні частот 26–37.5 ГГц. Результати експериментальних досліджень розробленої кераміки на основі облицювальної плитки з електропровідною добавкою 10, 20 і 30 мас. % з графіту. Для визначення параметрів взаємодії електромагнітного випромінювання зі зразками використовували модернізовану стандартну апаратуру – мікрохвильовий вимірювач коефіцієнта стоячої хвилі та послаблення П2-65. Фазовий склад матеріалу визначали методом рентгенофазового аналізу на дифрактометрі ДРОН-3М з CuK_{α} випромінюванням з нікелевим фільтром. Розроблені композиційні керамічні матеріали відповідають основним вимогам до експлуатації подібних матеріалів і можуть бути використані для послаблення високочастотного електромагнітного поля в приміщеннях, розташованих у зонах дії радіовипромінювання, а також з екологічною метою для зниження напруженості електромагнітного поля. за межами приміщень, де є джерела радіовипромінювання. Таким чином, розроблена композитна кераміка має характеристики, які дозволяють використовувати її в будівництві та в електронних пристроях з метою ефективного екранування шкідливого радіовипромінювання, а розроблену кераміку, згідно з класифікацією, можна віднести до радіопоглинаючої.

***Ключові слова**: електромагнітне випромінювання, радіопоглинаюча кераміка, електропровідні добавки, електрофізичні властивості, коефіцієнт пропускання, коефіцієнт відбиття, рентгенофазовий аналіз*

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Received 23.09.2022, accepted 05.06.2023