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Original paper

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ELECTROMAGNETIC RADIATION SHIELDING COMPOSITE COATINGS BASED ON POWDERED ALUMINA AND IRON OXIDE

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Abstract. The article presents the results of experimental substantiation of the method for improving the shielding properties of composite coatings based on powdered alumina (electrocorundum, alum earth), which consists in modifying the composition of such coatings by adding to it powdered iron oxide. This experimental substantiation consisted in the development of the technique for obtaining composite coatings based on powdered alumina and iron oxide, the manufacture of the experimental samples using the developed technique, measurements of electromagnetic radiation reflection and transmission coefficients values in the frequency range 0.7...17.0 GHz of the manufactured samples; implementation of the comparative analysis of the measured values with the similar values typical for the composite coatings filled with powdered alumina oxides, and composite coatings with the fillers such as powdered iron oxide. The obtained results revealed that by adding powdered iron oxide to the composite coatings based on powdered alumina oxides, it is possible to reduce by 1.0...8.0 dB their electromagnetic radiation transmission coefficient values in the frequency range 0.7...17.0 GHz. In addition, we found that the implementation of the proposed method allows one to decrease by 2.0...20.0 dB the electromagnetic radiation reflection coefficient values in the specified frequency range of the considered composite coatings, if such are applied to metal substrates. We propose to use the composite coatings, obtained on the base of the substantiated method, in order to ensure the electromagnetic compatibility of radio-electronic equipment.

Keywords: alum earth, electrocorundum, electromagnetic radiation, composite coating, iron oxide, shielding.

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Introduction

The paper [1] presents the results of the study targeted to experimental substantiation of the method for modifying the composition and thereby improving the shielding and radioabsorbing properties of non-combustible composite coatings based on powdered alumina (electrocorundum, alum earth), which consists in adding to such coatings the components characterized by conductive properties, in particular, in fixing fragments of insulated metallized polyethylene film on the surface of such coatings. The results of such study has shown that using the proposed method enables to reduce by 1.0...6.0 dB the electromagnetic radiation (EMR) reflection coefficient values in the frequency ranges 0.9...4.0 GHz and 11.0...17,0 GHz of the composite coatings based on powdered alumina and applied to metal substrates.

The study considered in this paper is developed from the study presented in paper [1]. Its aim was to substantiate experimentally the method for improving the shielding and radioabsorbing properties of composite coatings based on powdered alumina (electrocorundum, alum earth), which consists in modifying the composition of such coatings by adding the powdered materials

characterized by magnetic properties (in privacy, powdered iron oxide [2, 3]). The choice of powdered iron oxide as the material added to the composite coatings based on powdered alumina was due to its lower cost compared to analogues. The study says the powdered iron oxide is more advantageous in comparison with other materials characterized by magnetic properties for being a natural material [4].

To achieve this aim, the following tasks have been solved:

- the technique for the manufacture of composite coatings based on powdered alumina and iron oxide has been developed;
- experimental samples on the basis of composite coating made in accordance with the developed technique, as well as experimental samples have been formed on the basis of the composite coatings, one filled with powdered alumina and another one with powdered iron oxide;
- measurements of EMR reflection and transmission coefficients values of the formed experimental samples have been carried out;
- the comparative analysis of EMR reflection and transmission characteristics, obtained on the basis of the measurements results, has been implemented;
- recommendations for the practical use of the obtained research results have been made.

Experimental method

The developed technique for the manufacture of composite coatings based on powdered alumina and iron oxides includes the following stages.

Stage 1. Establishing the optimal volumetric ratio of powdered alumina, powdered iron oxide and a binder (water-based paint, aqueous alkaline sodium silicate solution or gypsum solution) in the manufactured composite coating in accordance with the method presented in [5], and taking into account that the content of powdered alumina in the composition of such coating should exceed the content of powdered iron oxide.

It was found that the optimal volumetric ratio of these three components is 3.0:2.0:5.0 parts.

Stage 2. Mixing the powdered alumina with the powdered iron oxide in the established optimal volumetric ratio.

Stage 3. Adding the binder to the mixture of powdered alumina and iron oxide.

Stage 4. Uniform distribution of particles of the mixture of powdered alumina and iron oxide over the volume of the binder added to it using a laboratory mixer.

Stage 5. Deposition with a spatula of a layer of the resulting mixture on a substrate surface.

Stage 6. Drying a layer of the mixture applied to the substrate surface under standard conditions [6].

Stage 7. Controlling the layer thickness of the mixture using an electronic micrometer.

Stage 8. If necessary, increase the thickness of the mixture layer by repeating the stages 5–7.

In accordance with the developed technique, the following experimental samples have been formed:

- the composite coating based on powdered electrocorundum, iron oxide and an aqueous alkaline solution of sodium silicate, applied to a cellulose substrate with a layer 3.0 mm thick (reference designation – sample 1);
- the composite coating based on powdered electrocorundum, iron oxide and an aqueous alkaline solution of sodium silicate, applied to a metal substrate with a layer 3.0 mm thick (reference designation – sample 2).

In addition, following the technique similar to the developed one, the following experimental samples have been formed:

- the composite coating based on powdered electrocorundum and an aqueous alkaline sodium silicate solution, applied to a cellulose substrate with a layer 3.0 mm thick (reference designation – sample 3);
- the composite coating based on powdered electrocorundum and an aqueous alkaline sodium silicate solution, applied to a metal substrate with a layer 3.0 mm thick (reference designation – sample 4);
- the composite coating based on powdered iron oxide and an aqueous alkaline sodium silicate solution, applied to a cellulose substrate with a layer 3.0 mm thick (reference designation – sample 5);
- the composite coating based on powdered iron oxide and an aqueous alkaline sodium silicate solution applied to a metal substrate with a layer 3.0 mm thick (reference designation – sample 6).

Measurements of EMR reflection and transmission coefficients values of the formed experimental samples have been carried out in the frequency range 0.7...17.0 GHz using a panoramic meter of reflection and transmission coefficients SNA 0.01–18 in accordance with the method presented in [7, p. 47].

Based on the results of such measurements, EMR reflection and transmission characteristics in the frequency range 0.7...17.0 GHz were obtained. A comparative analysis of the obtained characteristics has been carried out in the order presented in Table 1.

Table 1. The procedure for comparing EMR reflection and transmission characteristics of the experimental samples

Compared characteristics	The purpose of comparing the characteristics
EMR reflection and transmission characteristics of samples 1 and 3	Experimental substantiation of the prospects of using the proposed method to improve EMR shielding properties of composite coatings based on powdered alumina oxides
EMR reflection and transmission characteristics of samples 1 and 5	Experimental substantiation of the obtaining capability on the basis of the proposed method of the composite coatings with EMR shielding properties not worse than those characteristic of the coatings filled with powdered iron oxide or exceeding these properties
EMR reflection characteristics of samples 2 and 4	Experimental substantiation of the prospects of using the proposed method to improve radioabsorbing properties of composite coatings based on powdered alumina oxides
EMR reflection characteristics of samples 2 and 6	Experimental substantiation of the obtaining capability on the basis of the proposed method of the composite coatings with the radioabsorbing properties not worse than those characteristic of the coatings filled with powdered iron oxide or exceeding these properties

Results and their discussion

The frequency dependencies of EMR reflection and transmission coefficients in the range of 0.7...17.0 GHz of manufactured samples 1, 3 and 5 are presented in Fig. 1 and 2.

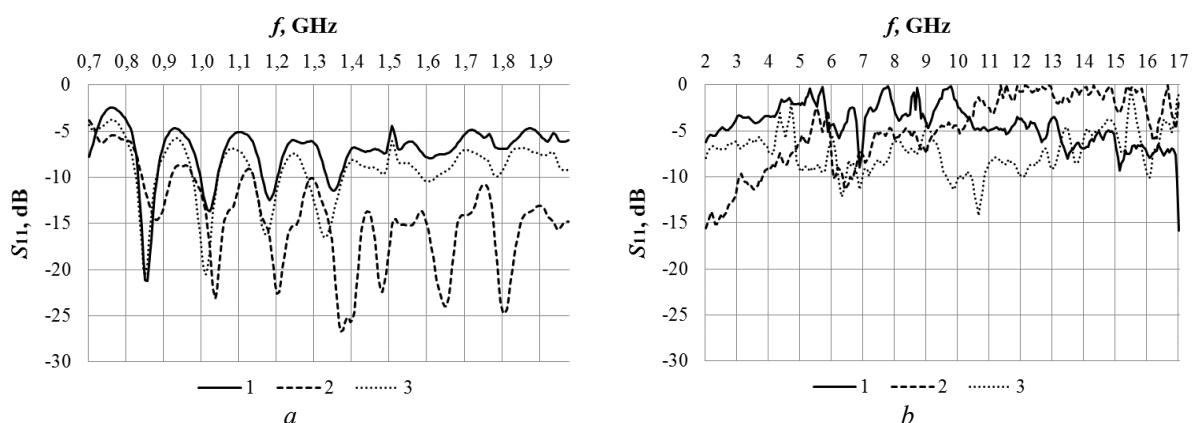


Fig. 1. Frequency dependencies of EMR reflection coefficient in the range 0.7...2.0 GHz (a) and 2.0...17.0 GHz (b) of the samples 1 (curves 1), 3 (curves 2) and 5 (curves 3)

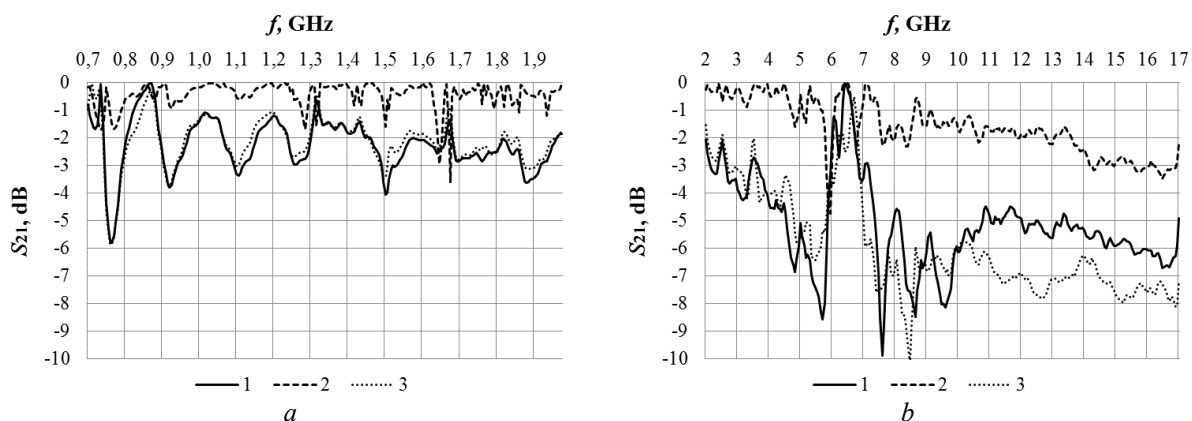


Fig. 2. Frequency dependencies of EMR transmission coefficient in the range 0.7...2.0 GHz (a) and 2.0...17.0 GHz (b) of the samples 1 (curves 1), 3 (curves 2) and 5 (curves 3)

Based on the results of comparing the characteristics shown in Fig. 1 and 2, which was performed in the order presented in Table 1, the following has been established.

1. The addition of powdered iron oxide to the composition of the composite coating filled with powdered alumina enabled to reduce by 1.0...8.0 dB EMR transmission coefficient values in the frequency range 0.7...17.0 GHz of such coating, which is due to an increase of 1.0...15.0 dB of EMR reflection coefficient values [8]. An increase of EMR reflection coefficient values of a composite coating based on powdered alumina as a result of adding powdered iron oxide to the composition of such coating is associated with an increase in its wave resistance [9, p. 142] due to the fact that the relative magnetic permeability of powdered iron oxide is greater than 1 [2, 3].

2. In the frequency ranges 0.7...14.0 GHz and 16.0...16.5 GHz, EMR reflection coefficient values of the composite coating filled with a mixture of powdered alumina and iron oxide, exceed by 1.0...8.0 dB the values of EMR reflection coefficient of the composite coating filled with powdered iron oxide. It could be due to a combination of the following phenomena:

- the energy of electromagnetic waves scattered by particles of the mixture of powdered alumina and iron oxide exceeds the energy of electromagnetic waves scattered by particles of powdered iron oxide, since the size of particles of powdered alumina is larger than the size of particles of powdered iron oxide [10, p. 123];

- interaction of electromagnetic waves, scattered by particles of the mixture of powdered alumina and iron oxide and characterized by a phase similar to the phase of an electromagnetic wave reflected from the "air – composite coating" interface, causes an increase in the amplitude of this wave.

In the frequency ranges 14.0...16.0 GHz and 16.5...17.0 GHz, EMR reflection coefficient values of the composite coating filled with a mixture of powdered alumina and iron oxide, are lower by 1.0...8.0 dB than EMR reflection coefficient values of the composite coating filled with powdered iron oxide. It could be due to the fact that the electromagnetic waves of the specified frequency ranges, scattered by the particles of the mixture of powdered alumina and iron oxide, are characterized by a phase different from the phase of the electromagnetic wave reflected from "air – composite coating" interface. In this regard, as a result of the interaction of the reflected wave with the scattered waves, its amplitude decreases.

EMR transmission coefficient values in the frequency range 0.7...10.0 GHz of the composite coating filled with a mixture of powdered alumina and iron oxide, are practically similar to the values of a similar parameter of the composite coating filled with powdered iron oxide. This feature may be due to a combination of the following phenomena:

- EMR transmission coefficient in the frequency range 0.7...10.0 GHz of the considered composite coatings is determined by the amplitude of the electromagnetic wave reflected from "air – composite coating" interface, the amplitudes of the electromagnetic waves scattered by the particles of the fillers of these coatings, as well as the energy losses of the EMR as a result of its propagation in the coating;

- EMR energy losses associated with its propagation in the composite coating filled with a mixture of powdered alumina and iron oxide are less than EMR energy losses associated with its propagation in the composite coating filled with powdered iron oxide, due to the fact that the value of the relative magnetic permeability of the latter is higher than that of the specified mixture;

- the difference between the magnitude of EMR energy losses associated with its propagation in the composite coating filled with powdered iron oxide, and between the magnitude of EMR energy losses associated with its propagation in the composite coating filled with a mixture of powdered alumina and iron oxide, is practically similar with the difference between the magnitude of the energy of electromagnetic waves scattered by the filler particles of the former and the latter coatings.

In the frequency range of 10.0...17.0 GHz, EMR transmission coefficient values of the composite coating filled with a mixture of powdered alumina and iron oxide, exceed, on average, by 3.0 dB EMR transmission coefficient values of the composite coating filled with powdered iron oxide. This can be associated with an increase in the difference between the amount of EMR energy losses associated with its propagation in the latter coating and the magnitude of the EMP energy losses associated with its propagation in the former coating.

The frequency dependencies of EMR reflection coefficient in the range 0.7...17.0 GHz of manufactured samples 2, 4 and 6 are presented in Fig. 3.

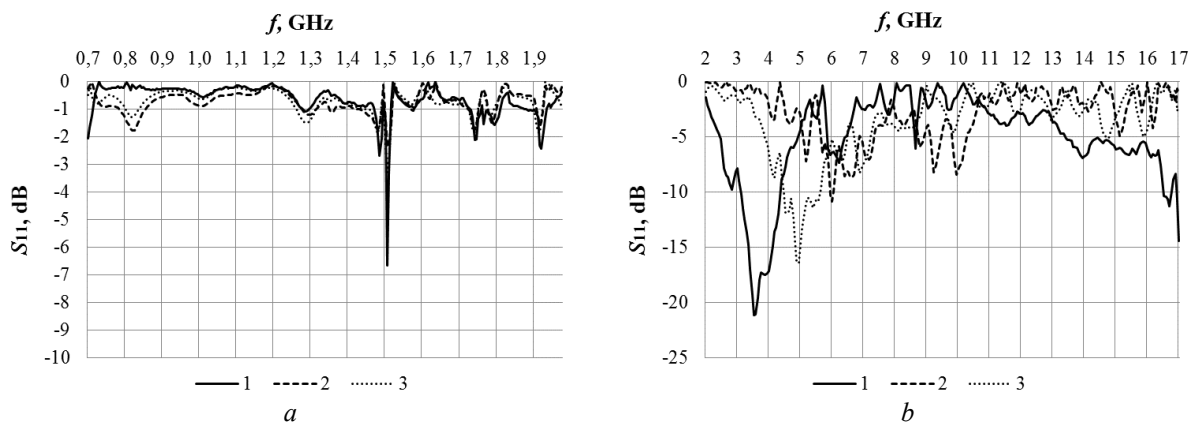


Fig. 3. Frequency dependencies of EMR transmission coefficient in the range 0.7...2.0 GHz (a) and 2.0...17.0 GHz (b) of the samples 2 (curves 1), 4 (curves 2) and 6 (curves 3)

Based on the results of comparison of the characteristics shown in Fig. 3, which was performed in the order presented in Table 1, the following has been established.

1. EMR reflection coefficient values in the frequency ranges 0.7...1.5 GHz, 1.52...2.0 GHz of the composite coating filled with powdered alumina and deposited on a metal substrate are practically similar to the values of the similar parameter of the composite coating a mixture of powdered alumina and iron oxide or powdered iron oxide and deposited on a metal substrate. This can be attributed to the fact that in the specified frequency range EMR reflection coefficient is determined to a greater extent by the amplitude of electromagnetic waves reflected from “composite coating – metal substrate” interface than by the amplitude of electromagnetic waves reflected from “air – composite coating” interface.

2. The addition of powdered iron oxide to the composite coating filled with powdered alumina enables to reduce by 2.0...20.0 dB EMR reflection coefficient values at a frequency of 1.5 GHz and in the frequency ranges 2.0...5.0 GHz, 11.0...17.0 GHz (provided that such coating is deposited on a metal substrate). The specified effect recorded at a frequency 1.51 GHz and in the frequency range 2.0...5.0 GHz, may be due to the phenomenon of natural ferromagnetic resonance associated with the magnetic properties of powdered iron oxide. In turn, the effect recorded in the frequency range 11.0...17.0 GHz may arise from the phenomenon of interaction in antiphase between electromagnetic waves reflected from “air – composite coating” interface and electromagnetic waves reflected from “composite coating – metal substrate” interface. Note that relative to EMR of the frequency range 3.0...4.0 GHz, the composite coating filled with a mixture of powdered alumina and iron oxide and deposited on a metal substrate is characterized by radioabsorbing properties, since its EMR reflection coefficient values in the specified frequency range are equal to or less than -10.0 dB.

3. In the frequency range 4.5...6.0 GHz, EMR reflection coefficient values of the composite coating filled with powdered iron oxide and deposited on a metal substrate is lower by 1.0...10.0 dB than the EMR reflection coefficient values of the composite coating filled with a mixture of powdered alumina and iron oxide and deposited on a metal substrate. This is due to the difference in the frequency value of natural ferromagnetic resonance associated with EMR interaction with each of these coatings.

Conclusion

The obtained results make it possible to conclude that adding 20.0 vol. % of powdered iron oxide to the composition of the composite coating filled with powdered alumina allows improving their EMR shielding properties in the frequency range 0.7...17.0 GHz and radioabsorbing properties in the frequency ranges 2.0...5.0 GHz, 11.0...17.0 GHz. In this case, the property of incombustibility of such coatings is preserved. Note that the cost of 1 kg of iron oxide is comparable to the cost of 1 kg of powdered alumina (electrocorundum, alumina), that is, the use of the proposed method will not lead to an increase in the cost of a composite coating based on such oxides. Composite coatings filled with a mixture of powdered alumina and iron oxide can be used in the manufacturing or improving the technical and operational properties of electromagnetic shields designed to ensure electromagnetic compatibility of radioelectronic equipment.

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Authors' contribution

Penialosa Ovalies D.I. has developed the method for manufacturing of composite coatings based on powdered alumina and iron oxides.

Boiprav O.V. has assisted in carrying out measurements, interpreting measurement results, as well as in writing the article.

Lynkou L.M. and Tumilovich M.V. have determined the relevance, aims and objectives of the research, the results of which are presented in the article.

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