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Charcoal-containing building materials for electromagnetic radiation shielding

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Abstract. The aim of the study presented in the current article was to experimentally substantiate the possibility of obtaining the cost effective building materials for electromagnetic radiation shielding by using powdered charcoal as a filler. Such charcoal properties as low cost and high carbon content (up to 90.0 wt.%) were the prerequisites for the study. To achieve the goal, a method for obtaining composite materials based on powdered charcoal and building gypsum was developed and experimentally substantiated by the authors. Further, the samples of charcoal-containing building materials were made according to the developed method and the electromagnetic radiation reflection and transmission coefficients values of the samples were measured in the frequency range of 0.7–17.0 GHz using scalar network analyzer. According to the measurements results, it was found that the average value of the electromagnetic radiation reflection coefficient in the specified frequency range of the materials produced in accordance with the presented method (when these materials thickness was equal to 1.0 cm) was –3.0 dB, and the average value of the electromagnetic radiation transmission coefficient was –25.0 dB. The studied materials are recommended for use in electromagnetic shielding of the rooms housing the electronic devices.

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1. Introduction

Nowadays the building materials for electromagnetic radiation shielding are one of the objects of scientific area dealing with the functional materials development and research. This is due to the combination of the following reasons:

1) expansion of the number of electronic devices used to solve industrial and household problems, and the increase in the level of the electromagnetic background associated with it (since in the course of their operation each of these devices forms and emits electromagnetic waves [1, 2] due to them containing antenna analogs);

2) the need for electromagnetic shielding of the rooms housing the electronic devices that are sensitive to interference (servers, medical equipment, measuring equipment, etc.) [2, 3].

Currently developed building materials suitable for electromagnetic radiation shielding are composites with the following combinations of components:

1) matrix and filler;

2) binder agent and filler.

The materials associated with the first combination, as a rule, are used as finishing panels for the walls of the rooms housing the electronic devices sensitive to interference. In such materials, porous substrates are their matrices, while iron, nickel, copper or carbon particles serve as their fillers. The technology obtaining such materials is based on deposition of these particles in the pores [4] or on the surface [5] of the matrices. Their main advantage is the possibility to produce finishing panels of complex shape on their basis (not flat and not associated with the regular geometric figures). For example, it's possible to obtain finishing panels, the surface of which contains a set of inhomogeneities interacting with and scattering the electromagnetic radiation. This is a very important property, especially when the shielded room should resemble an anechoic chamber. Moreover, such materials allow designing finishing panels of non-straight boundaries. This shape comes useful, when the room in need of shielding has uneven corners. In general, the shape of the panels, formed on the basis of the discussed materials, is defined by their matrices shape. However, the main disadvantage of such materials is technological complexity and high time consumption of their production. This disadvantage is critical, because the total square of the room might be comparable with the total square of the room walls, which should be covered by these panels, making it a challenge to cover everything.

The building materials suitable for electromagnetic radiation shielding and associated with the second of the presented combinations, are characterized by lower technological complexity compared with the materials of the first combination. This is due to the fact, that their production technology is based on the distribution of the particles or fibers, containing iron, nickel, copper or carbon, in the volume of binder agent, which is, as a rule, cement, building gypsum or polymer [6–11]. Such materials are used as building mixtures for covering the walls of the rooms housing interference-sensitive electronic devices with panels. These panels, compared with the matrix-and-filler panels, are characterized by regular (as a rule, rectangle or square) and flat shape.

It's necessary to stress, that carbon particles or fibers are a more promising source for the fillers in the composite panels. This is because metal powders (iron, nickel, copper etc.) give the composites high density and low mechanical strength [9]. This means, that such materials, when applied in the rooms housing interference-sensitive electronic devices, create a high load on the walls. In addition, such materials could be characterized by low adhesion to the walls.

Carbon particles and fibers, used as the fillers of the building materials, suitable for electromagnetic radiation shielding, are characterized by high cost, because the production of such fillers is based on the use of expensive components or equipment. This poses the scientific problem of searching or synthesis of low-cost carbon-containing fillers for obtaining cost effective building materials, suitable for electromagnetic radiation shielding. One of the variants of such fillers is presented in paper [12]. It is a mixture of tire waste and slag samples. To extend the results, achieved in the way of the indicated problem solving, the authors of the current paper set the following goal: experimentally substantiate the possibility of obtaining cost-effective building materials for electromagnetic radiation shielding by use powdered charcoal as a filler for such materials. To achieve the goal, the following tasks were solved:

1) the method for obtaining the materials based on powdered charcoal and building gypsum was developed and experimentally substantiated by the authors (the optimal volumetric ratio to mix powdered charcoal and building gypsum powder was established, and the equipment and accessories needed for the production were defined);

2) the samples of charcoal-containing building materials were made according to the developed method;

3) the electromagnetic radiation reflection (S_{11}) and transmission coefficients (S_{21}) values of the produced samples were measured and analyzed.

The prerequisites for the goal and tasks setting were the following charcoal properties:

- low cost, as charcoal is currently produced from wood-processing waste [13, 14];
- high carbon content (up to 90.0 wt.%), which determines its electrical conductivity property [15, pp. 259–267].

2. Methods

In the way of the development the method for obtaining of charcoal-containing building materials the authors defined the optimal volumetric ratio in which it is necessary to mix powdered charcoal and building gypsum powder. The following steps were made to solve the indicated task.

Step 1. Preparing nine mixtures of the powdered charcoal and building gypsum powder with use of the laboratory powder mixer. Each of the prepared mixtures differed in the volumetric ratio of its constituent powdered charcoal and dry building gypsum powder. The volumetric ratios of the indicated components were the following: 1:9, 1:4, 3:7, 2:3, 1:1, 3:2, 7:3, 4:1, 9:1.

Step 2. Adding water to every prepared mixture and mixing the first one with the second ones with use of laboratory liquid mixer. According to the research results, presented in the papers [16, 17], it was established, that the volume of the water added to the mixture must exceed 2 times the volume of the latter.

Step 3. Application of the mixtures, obtained on the step 2, on the cellulose substrates with use of spatula.

Step 4. Drying the mixtures, applied on the cellulose substrates, under the standard conditions [18].

Step 5. Visual control of the quality of the surfaces of the materials, obtained as a result of the steps 1–4 implementation. The used quality criterion – absence of cracks on the materials surfaces.

Step 6. Choosing the material, obtained as a result of the steps 1–4 implementation on the basis of the mixture, characterized by the optimal volumetric ratio of the powdered charcoal and building gypsum powder. The following criteria were used for choosing:

- there are no cracks on the material surface;
- the material is characterized by the biggest volumetric content of the powdered charcoal (the criterion was established due to the following two reasons: 1) there are no cracks on the several materials surfaces; 2) if the volumetric content of the powdered charcoal in the material is greater S_{21} value of the latter is less, due to the fact, that powdered charcoal is characterized by the electroconductivity property).

As a result of the described steps, it was established that the optimal volumetric ratio in which it is necessary to mix powdered charcoal and building gypsum powder when obtaining charcoal-containing building material is 2:3.

The authors determined that the following equipment and accessories needed to obtain of charcoal-containing building materials for electromagnetic radiation shielding: powder mixer, gypsum mixer, spatula, molds.

The developed by the authors method for obtaining of charcoal-containing building materials for electromagnetic radiation shielding includes the following steps.

Step 1. Mixing powdered charcoal and building gypsum powder in the established volumetric ratio (i. e. 2:3) with use of powder mixer.

Step 2. Adding 2 volume parts of the water in the mixture of powdered charcoal and building gypsum powder.

Step 3. Mechanical mixing of the water and the mixture of powdered charcoal and building gypsum powder with use of gypsum mixer.

Step 4. Application of the obtained material to the walls of the shielded room with use of spatula or filling the molds with the obtained material (in case, on the basis of this material, it is necessary to obtain plates for finishing of the shielded rooms walls).

The samples of charcoal-containing building materials were made according to the developed by the authors method. Table 1 presents the properties of these samples.

Table 1. The properties of the samples.

The sample name	Type of charcoal used for the sample making	The sample thickness, cm
1.1	Non-activated birch charcoal	0.3
1.2		0.5
1.3		1.0
2.1	Activated birch charcoal	0.3
2.2		0.5
2.3		1.0

The samples 1.1 and 2.1 were made by applying the mixture of the powdered charcoal, building gypsum powder and water (when the mixture was in the liquid phase) to cellulose substrates, the thickness of which was 3 mm. The indicated substrates are radiotransparency ones and due to this fact they do not impact on S_{11} and S_{21} values of the materials applied on them.

The samples 1.2, 1.3, 2.2 and 2.3 were manufactured by the following way:

1) filling full volume of the molds with the mixture of powdered charcoal, building gypsum powder and water (when the mixture was in the liquid phase); the molds length, width and thickness depend on the requirements to the corresponding parameters of the formed material; the used molds were made on the basis of flexible polymer radio-transparence material;

2) exsiccation of the mixture of powdered charcoal, building gypsum powder and water in the molds under the standard conditions [18];

3) extraction from the molds the obtained material.

S_{11} and S_{21} values of the made samples were measured in the near zone in the frequency range 0.7–17.0 GHz with use of scalar network analyzer. The indicated frequency range was chosen for the measurements performing due to the fact that the spectrum density of the electromagnetic radiation, emitted by the modern electronic equipment, is characterized by the maximum values in this range or such equipment operates on the frequencies from this range (for example, radars or equipment, used for information transmission and receiving via the wireless channels) [6].

Fig. 1, 2 shows the measurement schemes of S_{11} and S_{21} values of the made samples.

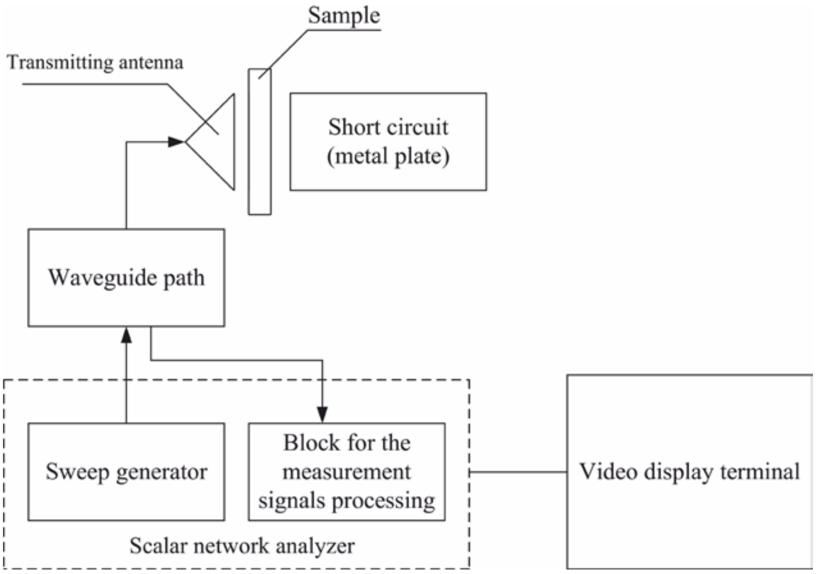

Figure 1. The measurement schemes of S_{11} values of the made samples.

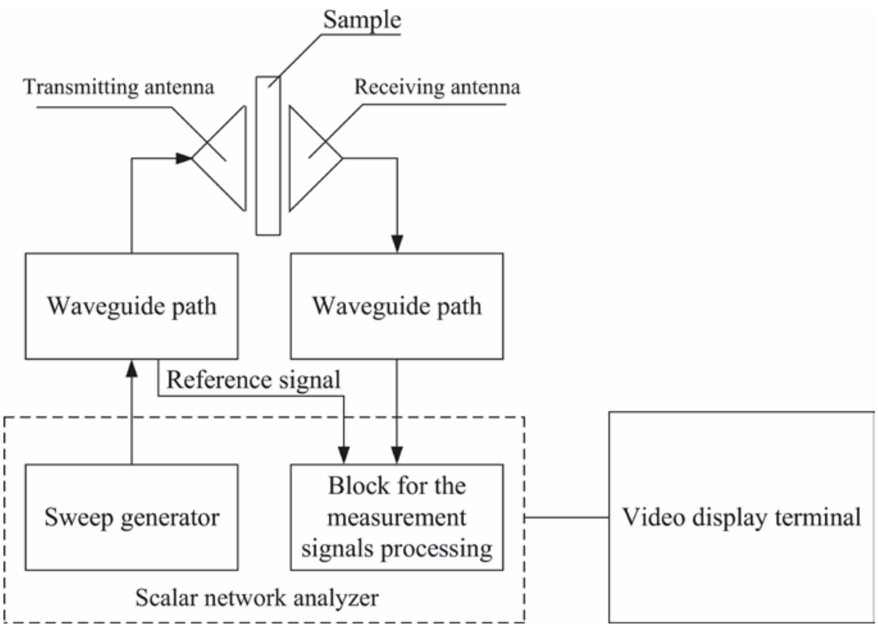

Figure 2. The measurement schemes of S_{21} values of the made samples.

3. Results and Discussion

Fig. 3–6 present S_{11} and S_{21} frequency dependences in the range 0.7…17.0 GHz of the made samples.

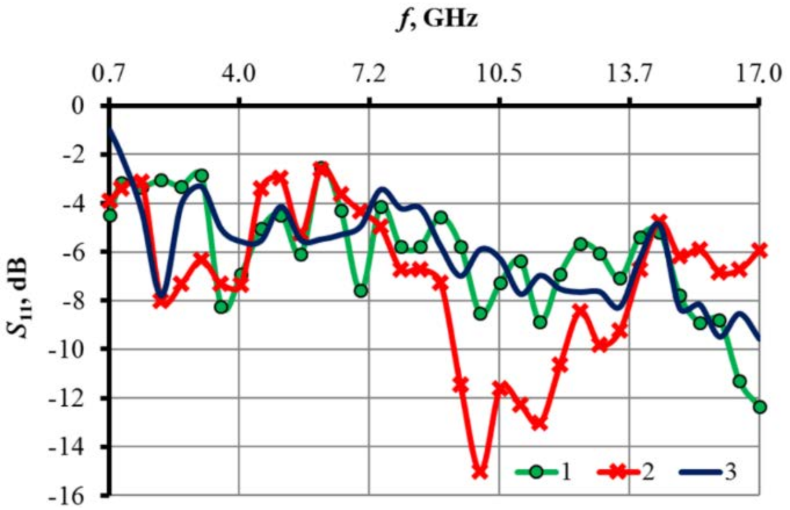

Figure 3. S_{11} frequency dependences in the range 0.7…17.0 GHz of the samples 1.1, 1.2 and 1.3 (curve 1, 2 and 3 respectively).

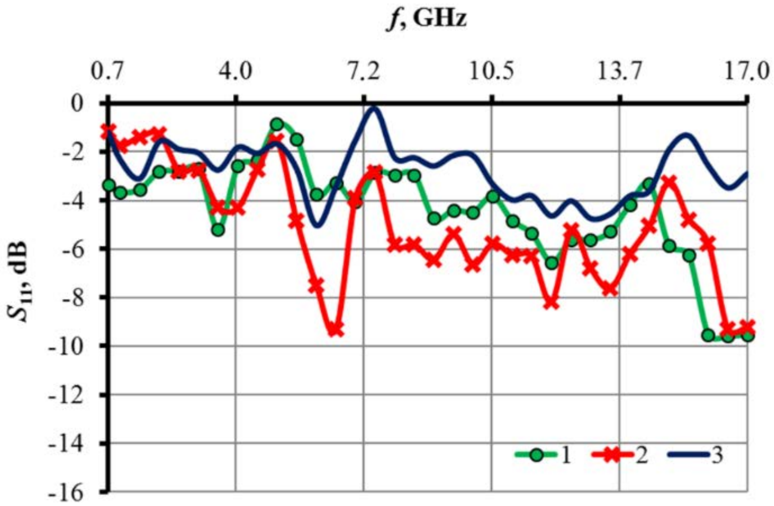

Figure 4. S_{11} frequency dependences in the range 0.7…17.0 GHz of the samples 2.1, 2.2 and 2.3 (curve 1, 2 and 3 respectively).

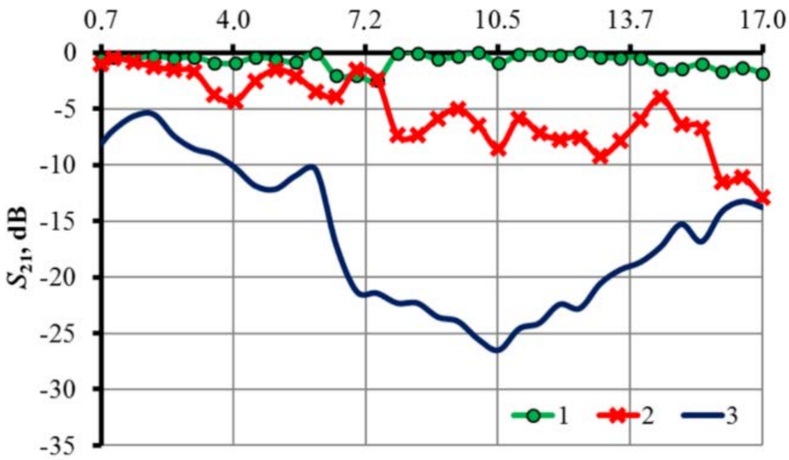

Figure 5. S_{21} frequency dependences in the range 0.7…17.0 GHz of the samples 1.1, 1.2 and 1.3 (curve 1, 2 and 3 respectively).

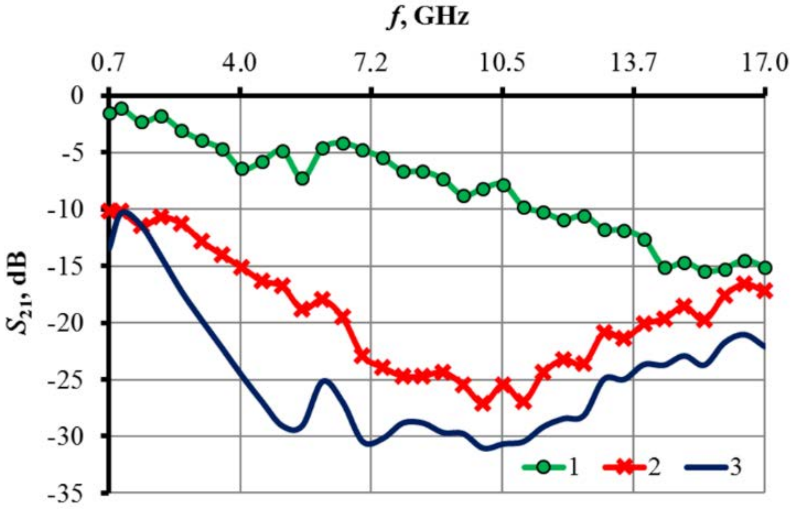

Figure 6. S_{21} frequency dependences in the range 0.7…17.0 GHz of the samples 2.1, 2.2 and 2.3 (curve 1, 2 and 3 respectively).

According to the results of comparative analysis of the frequency dependences presented in the Fig. 3 and 4 the following outcomes were obtained.

1. 0.3 material obtained according to the proposed method on the basis of non-activated birch charcoal is characterized by S_{11} values, changing from –3.0 to –12.0 dB. When such material thickness increases on 0.3 cm its S_{11} values increase on 1.0–7.0 dB. It's due to the fact that the phase difference of the electromagnetic waves reflected from the surfaces of 0.5 cm material and the short circuit (metal plate) is greater than the phase difference of the electromagnetic waves reflected from the surfaces of 0.3 cm material and short circuit (metal plate). When the considered material thickness increases to 1.0 cm its S_{11} values change no more than on 2.0 dB. It's due to the similarity of the phase difference of the electromagnetic waves reflected from the surfaces of 1.0 cm material and the short circuit (metal plate) and the phase difference of the electromagnetic waves reflected from the surfaces of 0.3 cm material and the short circuit (metal plate).

2. S_{11} values of the materials obtained according to the proposed method on the basis of activated birch charcoal is less by 2.0–5.0 dB compared to the materials obtained according to the proposed method on the basis of non-activated birch charcoal. It's due to the set of the following reasons:

– the materials obtained according to the proposed method on the basis of activated birch charcoal are characterized by the greater moisture content, compared to the materials obtained according to the proposed method on the basis of non-activated birch charcoal due to the fact that pore surface area of the activated charcoal is greater that pore surface area of the non-activated charcoal [19];
– material moisture containing increasing is the reason of its electrical conductivity increasing [20–22] and as a result the reason of increasing electromagnetic radiation reflection coefficient of this material [23–25].

According to the results of comparative analysis of the frequency dependences presented in Fig. 5 and 6 the following outcomes were obtained.

1. 0.3 cm material obtained according to the method of non-activated birch charcoal developed by the authors is characterized by S_{21} values, changing from –0.2 to –3.0 dB. S_{21} values of 0.5 cm and 1.0 cm materials obtained according to the developed method change correspondently from –1.0 to –8.0 dB and from –5.0 to –27.0 dB.

2. S_{21} values of the materials obtained according to the method of activated birch charcoal developed by the authors are greater on 2.0–15.0 dB compared to the materials obtained on the basis of non-activated birch charcoal. It's due to the set of the following reasons:

– the materials obtained according to the method of activated birch charcoal developed by the authors are characterized by the greater moisture content, compared to the materials obtained according to the proposed method of non-activated birch charcoal due to the fact that pore surface area of the activated charcoal is greater than pore surface area of the non-activated charcoal [19];

- an increase in material moisture content is the reason of its electrical conductivity increasing [21] and a result of increasing electromagnetic radiation losses provided by this material [26, 27].

4. Conclusion

The building materials obtained according to the method developed by the authors on the basis of non-activated birch charcoal are recommended for use in order to reduce the level of passive electromagnetic interference in rooms shielded with metals. At the same time, they should be applied in a layer 0.5 cm thick on the surface of metal sheets used for electromagnetic shielding of the rooms. This recommendation is due to the fact that S_{11} values of the developed materials, measured in short circuit mode, vary in the range from –3.0 to –15.0 dB (when these materials thickness equal to 0.5 cm), i.e., these materials at the specified thickness weaken the power of electromagnetic radiation reflected from by 2.0–32.0 times

The building materials obtained according the method developed by the authors on the basis of activated birch charcoal are recommended for use in electromagnetic shielding of the rooms housing interference sensitive electronic devices.

For this purpose, the developed materials should be used in one of the following forms:

1) in the form of plaster applied to the walls of the specified rooms (the optimal layer thickness of such plaster should be 1.0 cm);

2) in the form of plates with a thickness of 1.0 cm, intended for cladding of the walls of the specified rooms.

This recommendation is due to the fact that S_{21} values of the developed materials at their thickness of 1.0 cm vary from –10.0 to –30.0 dB, i.e., these materials provide an attenuation 10.0–1000.0 times the power of electromagnetic radiation interacting with them.

In general, on the basis of the achieved experimental results, it is possible to conclude, that the building materials obtained according to the method developed by the authors and their analogs presented in papers [7–11] are characterized by similar S_{21} values, due to the electrical conductivity property of powdered charcoal. S_{11} values of the building materials obtained according to the method developed by the authors are lower compared to the analogs. It's due to the following facts:

- the fractions size of the powdered charcoal is bigger compared to that of the powders, used for the analogs [7–11];
- if the powder fractions size is greater, the electromagnetic radiation energy dissipated by them is greater too [1].

Moreover, the building materials obtained according to the method developed by the authors are more cost-effective than their analogs, because they are produced from wood-processing waste, as it was indicated in the Introduction chapter of the paper.

Thus, the authors achieved the goal of the study.

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