Materials Physics and Mechanics. 2022;50(3): 420-430
Research article
http://dx.doi.org/10.18149/MPM.5022022_6

Submitted: July 5, 2022
Approved: October 6, 2022
Accepted: October 25, 2022

Flexible microwave absorbers based on powdered activated coconut charcoal and moisture-containing ceramsite

O.V. Boiprav✉**, S.E. Savanovich, E.S. Belousova**

Educational Establishment "Belarusian State University of Informatics and Radioelectronics", Minsk, Belarus

✉ smu@bsuir.by

Abstract. The article presents the results of the development of the technology for manufacturing flexible microwave absorbers, the fillers of which are powdered activated coconut charcoal and moisture-containing ceramsite, and the matrix for these materials' particles holding is polyurethane mastic. The results of the study of the regularities of the electromagnetic radiation interaction in the frequency range of 0.7-17.0 GHz with absorbers, manufactured according to the developed technology, depending on the size of the ceramsite particles contained in them, are presented. On the basis of these results, it was found that the studied absorbers, in comparison with absorbers, filled with moisture-containing ceramsite, are characterized by lower values of the electromagnetic radiation reflection coefficient in the frequency range of 0.7-17.0 GHz, reaching a value of -20.0 dB. In this case, the values of their electromagnetic radiation transmission coefficient in the indicated frequency range reach the value of -43.0 dB. Microwave absorbers, manufactured according to the developed technology, are promising for use in order to solve problems related to ensuring the functional reliability of radio electronic equipment, as well as ensuring environmental safety and information security.
Keywords: activated coconut charcoal, ceramsite, microwave absorber, reflection coefficient, transmission coefficient

Acknowledgements*. The research was carried out within the framework of research and development work "Development of electromagnetic radiation absorbers based on charcoal-containing and foiled materials for information and environmental security systems. Development of devices for interference suppression in the circuits of radio electronic and electrical equipment" under task 32 "Develop new materials, coatings and systems for the protection of radio electronic, optoelectronic and information equipment, biological objects from external energy impacts, ensuring their environmental and information safety, high functional reliability and efficiency" of subprogram 2 "Mastering new and high technologies in production" of the State Program of the Republic of Belarus "High technologies and equipment" for 2021-2025.*

Citation: Boiprav OV, Savanovich SE, Belousova ES. Flexible microwave absorbers based on powdered activated coconut charcoal and moisture-containing ceramsite. *Materials Physics and Mechanics*. 2022;50(3): 420-430. DOI: 10.18149/MPM.5032022_6.

© O.V. Boiprav, S.E. Savanovich, E.S. Belousova, 2022.
Publisher: Peter the Great St. Petersburg Polytechnic University
This is an open access article under the CC BY-NC 4.0 license (https://creativecommons.org/li-censes/by-nc/4.0/)

1. Introduction

Microwave absorbers are used to solve a number of technical problems associated with the operation of radio electronic equipment. These tasks can be roughly divided into three groups:

1) ensuring the functional reliability of radio electronic equipment [1,2];

2) ensuring environmental safety [3,4];

3) ensuring information security [5,6].

The solution to the problems of the first indicated group is aimed at radio electronic equipment protection from accidental exposure to electromagnetic interference (including ensuring the electromagnetic compatibility of radio electronic equipment). The solution is based on the use of the following products, made with microwave absorbers:

- covers for radio-electronic equipment housings;
- partitions for zonal division of space in the rooms, where radio electronic equipment is located;
- panels for cladding the walls of rooms, where radio electronic equipment is located.

The solution to the problems of the second indicated group is aimed at reducing the degree of electromagnetic radiation's influence on a person. The solution is based on the use of workwear or panels, made with microwave absorbers for cladding the walls of rooms, where people work.

The solution to the problems of the third indicated group is aimed to:

- information protection from leakage via the channel of spurious electromagnetic radiation and pickups;
- protection of information processing devices from deliberate electromagnetic interference;
- protection objects from detection by radar reconnaissance.

The solution is based on the use of the following products, made with microwave absorbers:

- cases for information processing devices;
- partitions for zonal division of space in rooms, where information processing devices are located;
- panels for cladding the walls of rooms, where information processing devices are located;
- camouflage coatings for the hulls of the objects, that may be targets of radar reconnaissance.

As a rule, the following requirements are imposed on the absorbers, which are currently used for the making of the listed products:

1) flexibility [7];

2) wide operating frequency range [8];

3) low (≤ -5.0 dB) values of the electromagnetic radiation reflection coefficient;

4) low (≤ -20.0 dB) values of the electromagnetic radiation transmission coefficient [8,9].

The first of these requirements is due to the fact that the products, the use of which is based on the solutions of the indicated technical problems, either characterized by a complex shape or intended to fixing on surfaces characterized by the presence of corners or kinks. The second of these requirements is due to the fact that the currently used radio electronic equipment (including information processing devices) is a source of electromagnetic radiation of a wide frequency range. The third and fourth of these requirements are due to the fact that high values of the electromagnetic radiation reflection coefficient of the listed products can cause passive electromagnetic interference. Such interference is formed due to the re-reflection of electromagnetic radiation from radio electronic equipment. It may affect the functional reliability of such equipment.

In connection with the foregoing, it can be stated that studies aimed at improving the existing microwave absorbers in order to ensure their compliance with the requirements presented are relevant.

The study, the results of which are presented in the article, was the development of the research work aimed at obtaining and improving microwave absorbers based on moisture-containing ceramsite. The advantages of the moisture-containing ceramsite used for the manufacture of microwave absorbers, characterized by the wide operating frequency range, are presented in [10,11]. The main of these advantages lies in the low cost of the ceramsite. The indicated advantage makes it possible to manufacture on the base of ceramsite the microwave absorbers, characterized by the corresponding property (including flexible ones [12]).

The aim of the study, the results of which are presented in the article, was to theoretically substantiate and experimentally confirm the technology for manufacturing microwave absorbers based on moisture-containing ceramsite, which are characterized by the flexibility property and lower values of the electromagnetic radiation reflection coefficient, in comparison with the absorbers, considered in [12]. In the course of the aim achieving, the following four scientific tasks have been solved:

1) selection and justification of methods for developing the technology for manufacturing microwave absorbers, that meet the requirement presented in the aim, and determining the procedure for the technology implementation;

2) laboratory implementation of the technology, using various types of the ceramsite (each type corresponds to a certain particle size of the ceramsite), as well as components, selected and justified as a result of the first task solving;

3) study of the regularities of the electromagnetic radiation interaction with absorbers, obtained as a result of the second scientific task solving, depending on the particle size of the ceramsite, contained in them;

4) comparative analysis of the electromagnetic radiation reflection coefficient values of the absorbers, obtained as a result of the second scientific task solving, with similar values, characterizing the absorbers presented in [12].

2. Materials and methods

In the course of solving the first scientific task, set to achieve the aim, a hypothesis has been put forward. According to this task, in order to decrease the electromagnetic radiation reflection coefficient values of the absorbers based on moisture-containing ceramsite, it is advisable to modify the outer structure of such material particles by forming on their surfaces the inhomogeneities. The size of these inhomogeneities should be comparable with the pore diameter of these particles. The hypothesis was based on information about the phenomena of microwave radiation propagation at the interfaces between media characterized by different wave impedance [13-15]. One such phenomenon is radiation scattering on the geometric inhomogeneities of these boundaries. The energy of radiation, scattered by the geometric inhomogeneities of the interfaces between media, characterized by different wave impedance, determines the energy of the radiation reflected from these boundaries: if the first one is higher, the second one is lower (and, therefore, the lower the values the electromagnetic radiation reflection coefficient, registered on the named boundaries) [15].

Forming of the inhomogeneities on the surfaces of materials (including powdered ones) can be implemented by using one of the following methods:

1) doping [16,17];
2) selective metallization [18,19];
3) 3D printing [20-22];
4) agglomeration of the particles with binders on surfaces [22,23].

For the formation of the inhomogeneities on the surfaces of the ceramsite particles, the fourth of the presented methods has been chosen. This is due to the fact, that it does not involve the use of special technological equipment. As a result, this method is characterized by the least time and financial costs for implementation. The particles of the powdered activated coconut charcoal have been selected for agglomeration with a binder on the ceramsite particles' surfaces. This choice was due to the following three reasons.

1. Powdered activated charcoal is characterized by high porosity (~ 95%). Therefore, it is characterized by high adhesion to binders [24].

2. The particle size of the powdered activated coconut charcoal is from 0.4 to 0.85 mm. Such size is comparable to the pore size of the ceramsite particles. This is the condition for strong adhesion of the first ones to the surfaces of the second ones [25].

3. The cost of 1 kg of powdered activated coconut charcoal is comparable to the cost of 1 kg of ceramsite. Therefore, the use of powdered activated coconut charcoal to modify the outer structure of the ceramsite particles will slightly increase the cost of the microwave absorber, based on them [26].

The developed technology is based on the technology for manufacturing the absorbers, considered in [12]. The procedure of the developed technology implementation includes the following steps.

Step 1. Solution preparation by mixing the sodium carboxymethyl cellulose aqueous solution with 20 % sodium chloride aqueous solution. The concentration of the sodium carboxymethyl cellulose aqueous solution, as well as the ratio, in which this solution should be mixed with 20 % sodium chloride aqueous solution, should be chosen such, that the dynamic viscosity of the solution, prepared from them, is 77.5 mPa·s at an ambient temperature of 20±3°C.

Step 2. Immersion wetting of the ceramsite particles, the size of which is at least 10.0 mm, with the prepared solution at atmospheric pressure of 101.3 kPa and an ambient temperature of 20±3°C.

Step 3. Preparation of the water-containing binder by mixing the sodium carboxymethyl cellulose aqueous solution with 40 % calcium chloride aqueous solution. The concentration of the sodium carboxymethyl cellulose aqueous solution, as well as the ratio, in which this solution is to be mixed with a 40 % calcium chloride aqueous solution, should be chosen such, that the dynamic viscosity of the water-containing binder, prepared from them, is 237.5 mPa·s at the ambient temperature of 20±3°C.

Step 4. Treatment of the ceramsite particles (step 2), with the prepared water-containing binder.

Step 5. Agglomeration of the powdered activated coconut charcoal particles on the surfaces of the ceramsite particles (step 4), by uniform mechanical mixing of the first ones with the second ones. The indicated components ratio should be that to create conditions for agglomeration of all particles of the powdered activated coconut charcoal on the surfaces of the ceramsite particles.

Step 6. Cutting two fragments from the fiberglass fabric, the shape and size of which are determined by the requirements for the shape, and size of the manufactured absorber.

Step 7. Cutting one fragment from a roll of a foiled polymer film, the shape, and size of which are determined by the requirements for the shape and size of the manufactured absorber.

Step 8. Fixing on the surface of one of the fiberglass fabric fragments (step 6) and the film fragment (step 7) using sprayed glue or double-sided adhesive tape. When fixing, the boundaries of the first of these fragments coincide with the boundaries of the second of specified fragments.

Step 9. Applying polyurethane mastic to the surface of the film fragment (step 7) with a layer of 6.0 mm thickness.

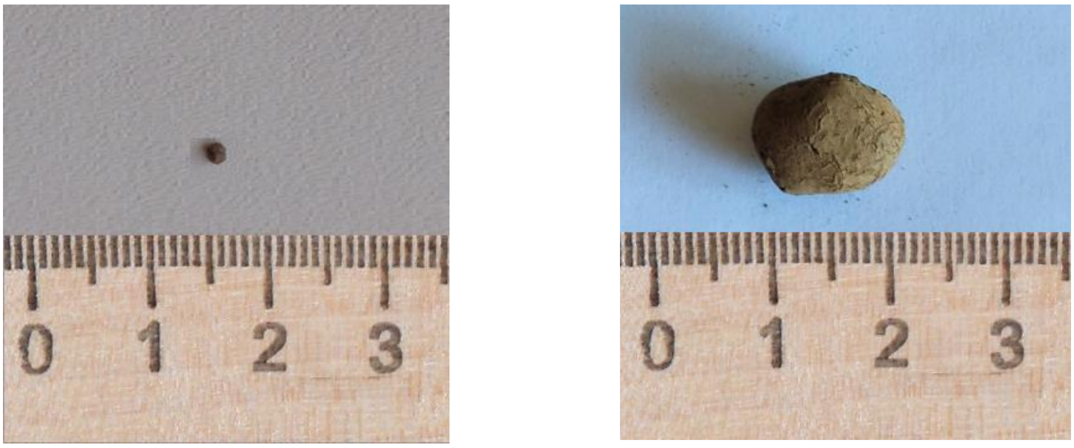
Step 10. Uniform distribution of the ceramsite particles (step 5) over the surface of the polyurethane mastic layer (step 9) on the surface of the film fragment.

Step 11. Applying polyurethane mastic to the surface of the second of the fiberglass fabric fragments, was obtained as a result of the step 6 implementation, with a layer of 4.0 mm thickness.

Step 12. Connecting the structure (steps 1-10) with the structure (step 11). When connecting, the first of these structures is oriented relative to the second one by the surface, on which the ceramsite particles are distributed. Also when connecting, the second of these structures is oriented relative to the first one by the surface, on which the polyurethane mastic is applied.

Step 13. Keeping under pressure the structure (steps 1-12).

As a result of solving the second scientific task, set to achieve the aim, according to the developed technology, two groups of microwave absorbers have been manufactured. Manufactured absorbers differed in the particle size of the ceramsite, included in their composition. Absorbers of group 1 included commercially produced ceramsite sand with a particle size of 1.0 to 2.0 mm. Absorbers of group 2 included ceramsite gravel with a particle size of 10.0 to 20.0 mm. Figure 1 shows the appearance of the particles of ceramsite sand and ceramsite gravel.

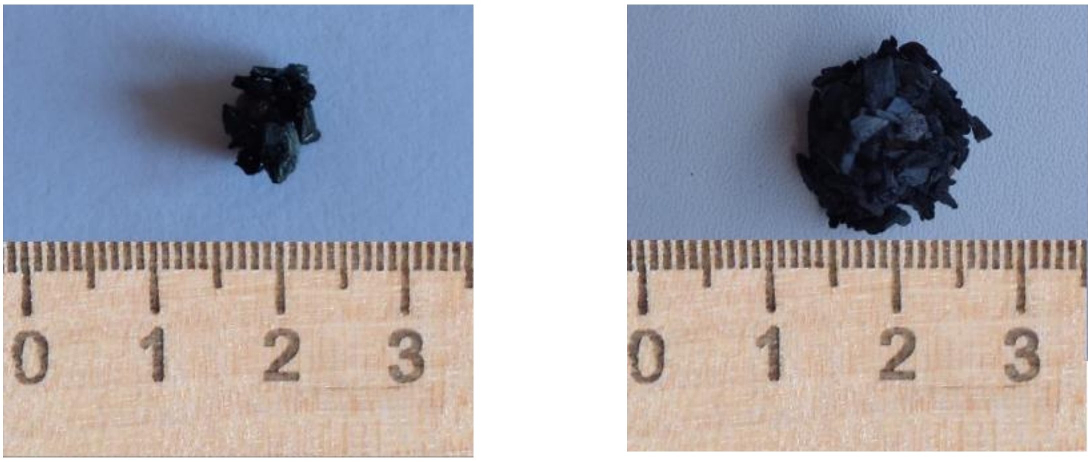


a) b)

Fig. 1. The appearance of the ceramsite sand particle (a) and ceramsite gravel particle (b)

Also, in the course of solving the second scientific task, set to achieve the aim, was determined the following. All particles of powdered activated coconut charcoal, when uniformly mechanically mixed with the ceramsite particles, treated with the water-containing binder, agglomerate on the surfaces of these particles, if the mass ratio of the powdered activated coconut charcoal particles and the ceramsite particles, treated with the water-containing binder, -7:10.

Figure 2 shows the appearance of the ceramsite sand and ceramsite gravel particles, treated with the water-containing binder, on the surfaces of which the powdered activated coconut charcoal particles are agglomerated.



a) b)

Fig. 2. The appearance of the ceramsite sand (a) and ceramsite gravel (b) particles, treated with the water-containing binder, on the surfaces of which the powdered activated coconut charcoal particles are agglomerated

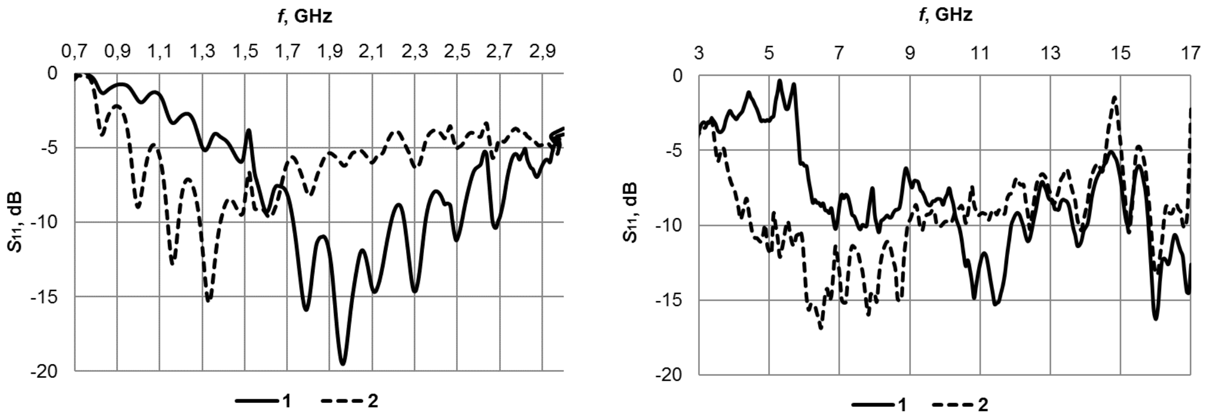
To solve the third scientific task, set to achieve the aim, measurements of the electromagnetic radiation reflection (S_{11}) and transmission (S_{21}) coefficient values of the manufactured absorbers were performed. In this case, a panoramic meter of reflection and transmission coefficients SNA 0.01-18 was used. The measurements were carried out in the frequency range of 0.7-17.0 GHz according to the technique, described in [27]. The choice of the frequency range for the measurements performing was due to the fact, that it corresponds to the most high-amplitude components of the electromagnetic radiation spectrum of modern radio electronic equipment [28].

Based on the measurement results, the frequency dependences of the electromagnetic radiation reflection and transmission coefficients of the manufactured absorbers have been plotted.

3. Results and Discussion

Frequency dependences of the electromagnetic radiation reflection coefficient in the range of 0.7-17.0 GHz of the absorbers, manufactured according to the developed technology, are shown in Fig. 3.

It follows from Fig. 3, that the electromagnetic radiation reflection coefficient values in the frequency range of 0.7-3.0 GHz of absorbers of group 1 vary from -1.0 to -20.0 dB, and absorbers of group 2 – from -1.0 to -15.0 dB. In the frequency range of 3.0-17.0 GHz, the electromagnetic radiation reflection coefficient values of these absorbers vary accordingly within the following limits: from -1.0 to -15.0 dB and from -3.0 to -17.0 dB. At the same time, it should be noted, that the average value of the electromagnetic radiation reflection coefficient in the frequency range of 0.7-3.0 GHz for the absorbers of group 1 is -5.9 dB, and for the absorbers of group 2 is -7.2 dB. In the frequency range of 3.0-17.0 GHz, the indicated parameter values for the absorbers are practically equivalent and amount to -9.0 dB and -8.0 dB, respectively. Absorbers of group 1 are characterized by a higher average value of the electromagnetic radiation reflection coefficient in the frequency range of 0.7-3.0 GHz, in comparison with the absorbers of group 2 due to the following set of these absorbers features.



a) b)

Fig. 3. Frequency dependences of the electromagnetic radiation reflection coefficient in the range of 0.7-3.0 GHz (a) and 3.0-17.0 GHz (b) of the absorbers of group 1 (curves 1) and the absorbers of group 2 (curves 2)

1. The mass of the ceramsite particles, included in a unit volume of absorbers of group 1, exceeds the mass of the ceramsite particles, included in a unit volume of absorbers of group 2. This is due to the fact, that the bulk density of the ceramsite particles, on the basis of which the absorbers of group 1 are made, is higher than the bulk density of the ceramsite particles, on the basis of which the absorbers of group 2 are made.

2. In connection with the first indicated feature, absorbers of group 1 contain more powdered activated coconut charcoal than absorbers of group 2.

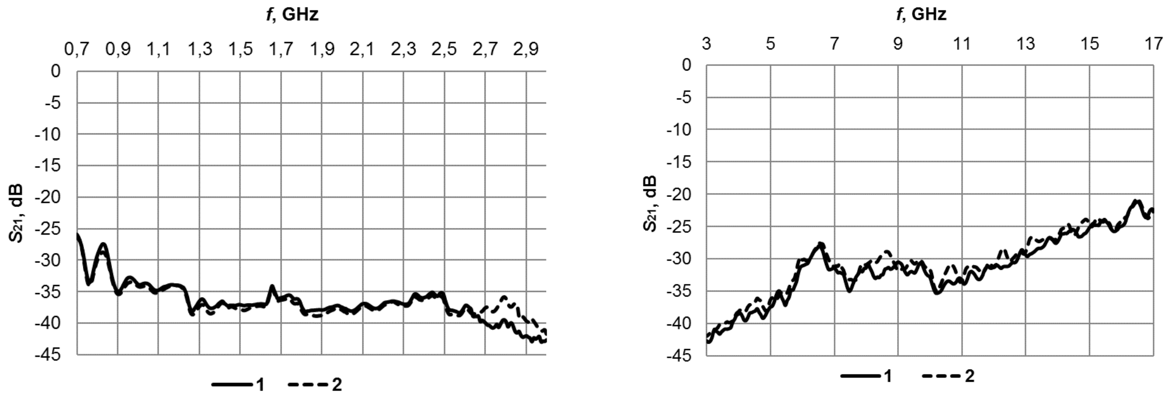
3. In connection with the second indicated feature, the electrical conductivity of absorbers of group 1 is higher than the electrical conductivity of absorbers of group 2.

The frequency bands, in which the electromagnetic radiation reflection coefficient values of the absorbers of group 1 are less than -5.0 dB are from 1.5 to 2.9 GHz and from 10.0 to 17.0 GHz. Similar frequency bands specific to the absorbers of group 2 are from 1.0 to 2.2 GHz, from 4.0 to 14.0 GHz, and from 15.0 to 17.0 GHz. Thus, electromagnetic radiation absorbers, manufactured according to the developed technology, are characterized by a wide operating frequency range. At the same time, it should be noted that the total bandwidth, in which the electromagnetic radiation reflection coefficient values of the absorbers of group 2 are less than -5.0 dB, exceeds the total width of the frequency bands, in which the electromagnetic radiation reflection coefficient values of the absorbers of group 1 are less than -5.0 dB This may be due to the following set of these absorbers features.

1. The ceramsite, on the basis of which the absorbers of group 2 are made, is characterized by a wider granulometric composition, in comparison with ceramsite, on the basis of which the absorbers of group 1 are made.

2. In connection with the first indicated feature, the number of wavelengths in the frequency range of 0.7-17.0 GHz, comparable to the particle sizes, which are parts of the absorbers of group 2, exceeds the number of wavelengths in the specified frequency range, comparable to the particle sizes, which are part of the absorbers of group 1.

The frequency dependences of the electromagnetic radiation transmission coefficient in the range of 0.7-17.0 GHz of the absorbers, manufactured according to the developed technology, are shown in Fig. 4.



a) b)

Fig. 4. Frequency dependences of the electromagnetic radiation transmission coefficient in the range of 0.7-3.0 GHz (a) and 3.0-17.0 GHz (b) of the absorbers of group 1 (curves 1) and the absorbers of group 2 (curves 2)

It follows from Fig. 4, that the electromagnetic radiation transmission coefficient values in the frequency range of 0.7-17.0 GHz of the absorbers of group 1 vary from -20.0 to -43.0 dB and are practically equivalent to the similar parameter values, characterizing the absorbers of group 2. This is due to the fact, that the foiled polymer film, which is part of the studied absorbers, makes a greater contribution to the electromagnetic radiation energy weakening, provided by them, than particles of the ceramsite, treated by the water-containing binder, and powdered activated coconut charcoal.

In the course of solving the fourth scientific task, set to achieve the aim, it was found that the electromagnetic radiation reflection coefficient values in the frequency range of 0.7-17.0 GHz of the absorbers, manufactured according to the developed technology, are lower on average 5.0 dB, than the similar parameter values, characterizing the absorbers presented in [12].

4 .Conclusion

Thus, microwave absorbers, manufactured according to the developed technology, are characterized by:

- the flexibility property (due to the fact that, according to the developed technology, the matrix for holding the ceramsite particles with powdered activated coconut charcoal particles, agglomerated on their surface, is made on the basis of polyurethane mastic);
- the wide operating frequency range (due to the fact that the composition of the absorbers, manufactured according to the developed technology, includes particles, whose sizes are comparable to a large number of microwave wavelengths);
- the electromagnetic radiation reflection and transmission coefficients values in the frequency range of 0.7-17.0 GHz, reaching values of -20.0 dB and -43.0 dB, respectively (due to the fact, that absorbers, manufactured according to the developed technology, include the particles, that provide the scattering of the electromagnetic radiation of the specified frequency range, and also includes a foiled polymer film);
- lower values of the electromagnetic radiation reflection coefficient in the frequency range of 0.7-17.0 GHz, in comparison with absorbers, considered in [12] (due to the fact that on the surface of the ceramsite particles, which are the part of the absorbers, manufactured according to the developed technology, the powdered activated coconut charcoal particles are agglomerated and provide additional scattering of electromagnetic radiation, interacting with such absorbers).

In connection with the foregoing, we can conclude, that the aim of the study, the results of which are presented in the article, has been achieved, and the hypothesis put forward in the course of solving the first scientific task, set to achieve the aim, has been confirmed.

Microwave absorbers, manufactured according to the developed technology, seem promising for use in order to ensure the functional reliability of radio electronic equipment, as well as to ensure environmental safety and information security. At the same time, on the basis of these absorbers, it is most expedient to manufacture the following products, respectively:

- partitions for zonal division of space in the rooms, where radio electronic equipment is located;
- panels for cladding the walls of the rooms, where people work;
- modules, designed to be fixed or placed on the hulls of the objects, that may be targets of radar reconnaissance.

References

1. Liang C, Gu Z, Zhang Y, Ma Z, Qiu H, Gu J. Structural Design Strategies of Polymer Matrix Composites for Electromagnetic Interference Shielding: A Review. *Nano-Micro Letters*. 2021;13: 181.
2. Abbasi H, Antunes M, Velasco JI. Recent advances in carbon-based polymer nanocomposites for electromagnetic interference shielding. *Progress in Material Science*. 2019;103: 319-373.
3. González M, Pozuelo J, Baselga J. Electromagnetic Shielding Materials in GHz Range. *The Chemical Record*. 2018:18(7-8): 1000-1009.
4. Wang X-Y, Liao S-Y, Wan Y-J, Zhu P-L, Hu Y-G, Zhao T, Sun R, Wong C-P. Electromagnetic interference shielding materials: recent progress, structure design, and future perspective. *Journals of Materials Chemistry C*. 2022;10(1): 44-72.
5. Hayashi Y-I, Homma N. Introduction to Electromagnetic Information Security. *IEICE Transactions on Communications*. 2019;1: 40-50.
6. Inigo C. An introduction to cybersecurity at physical layer: Obstacles at radio channel to mitigate hackers' chance. *Elektronika ir Elektrotechnika*. 2020;26(6): 58-65.
7. Cheng J, Li C, Xiong Y, Zhang H, Raza H, Ullah S, Wu J, Zheng G, Cao Q, Zhang D, Zheng Q, Che R. Recent Advances in Design Strategies and Multifunctionality of Flexible Electromagnetic Interference Shielding Materials. *Nano-Micro Letters*. 2022;14: 80.
8. Majidzadeh M, Ghobadi C, Nourinia J. Ultra Wide Band Electromagnetic Shielding Through a Simple Single Layer Frequency Selective Surface. *Wireless Personal Communications*. 2017;95: 2769-2783.
9. Afilipoaei C, Teodorescu-Draghicescu H. A Review over Electromagnetic Shielding Effectiveness of Composite Materials. *Proceedings*. 2020;63(1): 23;
10. Savanovich SE, Borbotko TV. Effect of Viscosity of Aqueous Sodium Chloride Solution, Introduced Into Pores Of Expanded Clay, On Its Radioabsorbing Properties. *Vestsi Natsyyanal’nai akademii navuk Belarusi. Seryya fizika-technichnych navuk.* 2016;2: 115-119. (In Russian)
11. Borbotko TV, Savanovich SE. Influence of water content of expanded clay on the reflection coefficient of electromagnetic shield. *Vestsi Natsyyanal’nai akademii navuk Belarusi. Seryya fizika-technichnych navuk.* 2020;66(1): 93-100. (In Russian)
12. Savanovich SE, Borbotko TV. Electromagnetic shield design based on pseudooval scattering elements for information protection from leakage via the electromagnetic channel. *Vestsi Natsyyanal’nai akademii navuk Belarusi. Seryya fizika-technichnych navuk*. 2022;67(2): 214-221.

13. Peña O, Pal U. Scattering of Electromagnetic Radiation by a Multilayered Sphere. *Computer Physics Communications*. 2009;180(11): 2348-2354.
14. Brath M, Ekelund R, Eriksson P, Lemke O, Buehler SA. Microwave and Submillimeter Wave Scattering of Oriented Ice Particles. *Atmospheric Measurement Techniques*. 2020;13: 2309-2333.
15. Fung AK, Chen KS. *Microwave Scattering and Emission Models for Users*. Artech House; 2009.
16. Cojocaru B, Avram D, Kessler V, Parvulescu V, Seisenbaeva G, Tiseanu C. Nanoscale insights into doping behavior, particle size and surface effects in trivalent metal doped SnO_2. *Scientific Reports*. 2017;7: 9598.
17. Hasan F, Kim J, Song H, Sung JH, Kim J, Yoo H. Effect of Particle Size and Doping on the Electrochemical Characteristics of Ca-doped $LiCoO_2$ Cathodes. *Journal of Electrochemical Science and Technology*. 2022;11(4): 352-360.
18. Camargo MK, Uebel M, Kurniawan M, Ziegler KF, Seiler M, Grieseler R, Schmidt U, Barz A, Bliedtner J, Bund A. Selective Metallization of Polymers: Surface Activation of Polybutylene Terephthalate (PBT) Assisted by Picosecond Laser Pulses. *Advanced Engineering Materials*. 2022;24(4): 2100933.
19. Jo S, Akin S, Park MS, Jun MBG. Selective metallization on glass surface by laser direct writing combined with supersonic particle deposition. 2022;31: 64-68.
20. Lores A, Azurmendi N, Agote I, Zuza E. A Review on Recent Developments in Binder Jetting Metal Additive Manufacturing: Materials and Process Characteristics. *Powder Metallurgy*. 2019;62(5): 267-296.
21. Bai Y, Wagner G, Williams C. Effect of Particle Size Distribution on Powder Packing and Sintering in Binder Jetting Additive Manufacturing of Metals. *Journal of Manufacturing Science and Engineering*. 2017;139(8); 2017.
22. Alsaqoor S, Borowski G, Alahmer A, Beithou N. Using of Adhesives and Binders for Agglomeration of Particle Waste Resources. *Advances in Science and Technology – Research Journal*. 2022;16(3): 124-135.
23. Van Netten K, Borrow DJ, Galvin KP. Fast Agglomeration of Ultrafine Hydrophobic Particles Using a High-Internal-Phase Emulsion Binder Comprising Permeable Hydrophobic Films. *Industrial & Engineering Chemistry Process Design and Development*. 2017;56(38): 10658-10666.
24. Mohd Iqbaldin MN, Khudzir I, Mohd Azlan MI, Zaidi AG, Surani B, Zubr Z. Properties of Coconut Shell Activated Carbon. *Journal of Tropical Forest Science*. 2013;25(4): 497-503.
25. Leman AS, Shahidan S, Senin MS, Hannan NIRR. A Preliminary Study on Chemical and Physical Properties of Coconut Shell Powder as a Filler in Concrete. *IOP Conference Series: Materials Science and Engineering*. 2016;160: 012059.
26. Chopngam K, Luengchavanon M, Khangkhamano M, Chetpattananondh K, Limbut W. Coating Activated Carbon from Coconut Shells with Co_3O_4/CeO_2 for High-Performance Supercapacitor Applications: an Experimental Study. *BioResources*. 2021;16(4): 8022-8037.
27. Boiprav OV, Grinchik NN, Pukhir GA. Experimental Substantiation of the Possibility of Hydrolytic Lignin Using in the Architectural Electromagnetic Shielding Systems. *Materials Physics and Mechanics*. 2022;48(1): 124-135.
28. Abdul-Al M, Amar ASI, Elfergani I, Littlehales R, Parchin NO, Al-Yasir Y, See CH, Zhou D, Abidin ZZ, Alibakhshikenari M, Zebiri C, Elmegri F, Abusitta M, Ullah A, Abdussalam FMA, Rodriguez J, McEwan NJ, Noras JM, Hodgetts R, Abd-Alhameed RA. Wireless Electromagnetic Radiation Assessment Based on the Specific Absorption Rate (SAR): A Review Case Study. *Electronics*. 2022;11(4): 511.

THE AUTHORS

Boiprav O.V.
e-mail: smu@bsuir.by
ORCID: 0000-0002-9987-8109

Savanovich S.E.
e-mail: svetasav@bsuir.by
ORCID: 0000-0001-7977-8031

Belousova E.S.
e-mail: belousova@bsuir.by
ORCID: 0000-0001-9834-6074