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The composite facing material for electromagnetic fields shielding

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Abstract. The facing material was developed for the purpose of shielding man-made electromagnetic fields in production working and domestic conditions. The facing material was designed on the base of latex and fine iron ore concentrate as filler. The experimental data on shielding of electromagnetic fields of ultrahigh frequencies and magnetic field of industrial frequency were obtained for different material thicknesses and concentration of screening particles. The significant increase of the shielding coefficients was established and explained by the manifestation of the percolation effect - the increase of the material conductivity at the critical concentration of the conductive component. The calculation apparatus for determining the dependence on the shielding properties of the material on the concentration of shielding substance was proposed. The method of the screening substance critical concentration calculation is shown to enable designing materials of lower thickness, weight and self-cost.

1. Introduction

In the context of increasing anthropogenic impact on environment, much attention is paid to the protective properties of facing and decorative construction materials. Electromagnetic fields of anthropogenic origin are one of the most significant physical factors of adverse effects on humans. The most effective protection against their impact in buildings and structures is shielding. But the use of metal screens is not always possible. In many cases, it is technically non-feasible to mount the shield surface. In addition, these designs are complex, heavy and unaesthetic. In such conditions, especially for buildings that are already in operation, the most rational is the application of facing materials that prevent the penetration of electromagnetic fields of technogenic origin into residential, industrial buildings and separate premises. Such materials must have certain properties: sufficient efficiency in the critical frequency ranges of electromagnetic fields, applicability (ease of lining surfaces of different configurations, low mass and thickness), and reasonable cost. Traditional metallic shielding materials do not meet modern requirements, so the most promising materials for shielding electromagnetic fields



of the wide frequency range are composite structures suitable for manufacturing electromagnetic screens with controlled protective properties.

2. Analysis of previous research

Much attention is currently paid to the development of composite materials for shielding electromagnetic fields. Most of them are designed for specific applications. In [1], the results of the development of the material with carbon nanotubes and graphene as shielding substances are presented. This material is intended for shielding electromagnetic fields only of ultra-high and high frequencies. In addition, it is expensive because of the high cost of the filler.

The same applies to the study [2], which shows the results of shielding the electromagnetic field with the frequency range of 8.2-12.4 GHz. The other paper describes the results of the development and properties study of the material for shielding electromagnetic fields in computers [3]. The use of composites based on carbon nanostructures is conditioned by their high efficiency in high-frequency spectrum [4]. Similar results were obtained in the study [5], in which iron-nickel ferrite particles were used as filler in the polymer matrix. This option is more acceptable because of greater availability of ferrite structures.

The main task in the protection against the influence of electromagnetic fields of ultra-high frequencies is to reduce the reflection coefficients. It is possible with the use of multilayer material [6]. But in manufacturing such surfaces it is necessary to maintain precisely the thickness of the layers, one of which must have the thickness equal to the quarter of the incident wave length. That is, such coatings are narrowband. Such facing could be applied for limited and specific tasks. Much attention is paid to the development of textile materials for shielding electromagnetic fields. In [7], a carbon fiber based material containing copper nanoparticles was described. Possessing high efficiency, such material, however, has great value. The study [8] describes the creation and testing of the material based on natural textile material soaked with magnetic fluid containing ferromagnetic nanoparticles. This material is highly efficiency for shielding magnetic and electric fields of industrial frequency (up to 8.6 - 8.9) and is suitable for manufacturing protective suits. Advantage of protective fabrics is small thickness, but for facing walls of buildings and rooms they are not suitable. In the analytical work [9], the efficiency and feasibility of using electromagnetic screens based on modified powder, nanostructured and film materials were analyzed. It is concluded that shielding surfaces should be produced for individual frequencies or ranges. This is unacceptable in the context of exposure to broadband electromagnetic fields. In [10] the results of development and investigation of the efficiency of metal-polymeric materials and shielding of electromagnetic fields of ultra-low and ultra-high frequencies are presented. The advantage of the design is the solidity of the material and small thickness (up to 10 mm). The screening substance used was iron ore, accumulated in the filters when grinding iron ore. There are many non-metallic and non-magnetic impurities in this material, so the shielding coefficients are not sufficient when the content of the shielding substance is low. But the direction of the work - the creation of materials for shielding electromagnetic fields of the most critical frequencies and frequency bands – is very promising. This requires the selection of the shielding substance of the desired electrophysical properties and dispersion and testing of protective properties of the composite with different content of shielding particles in the polymer matrix.

3. Problem statement

The aim of the study is to develop a composite metal-polymer material suitable for facing wall surfaces to shield electromagnetic fields of critical frequencies and frequencies ranges. To achieve this goal, the following main tasks are defined:

- to determine the material for manufacturing the polymeric material matrix and the shielding filler, as well as to study the filler dispersion;
- to develop manufacturing technology for material with different content of shielding filler;
- to study the shielding coefficients of the material for the magnetic field of industrial frequency and the electromagnetic field of ultra-high frequency;

- to analyze the obtained results and determine approaches to the design of electromagnetic screens with the required protective properties and promising areas of research to improve their efficiency.

4. Methods and materials

The shielding coefficients of the shielding materials (the ratio of the field strength (energy flux density) of the field source to the values of these parameters in the protected area) were determined by the method of direct measurements. Spectran 5035 Electromagnetic Spectrum Analyzer (Germany) was used to measure the magnetic field strengths at the industrial frequency. The maximum basic error of measurements did not exceed 1 dB. A geometrically closed cubic-shaped screen of $0.2 \times 0.2 \times 0.2$ m in size was used to measure the material's shielding coefficient for the magnetic field of industrial frequency. To determine the ultra-high frequency electromagnetic field shielding coefficients (2.4-2.6 GHz), the 0.3×0.3 m flat screen was used, it closed the window in a solid metal sheet without any gaps, which would prevent the electromagnetic field from entering the screen. During the measurements the background values of the industrial frequency magnetic field did not exceed $0.13 \mu\text{T}$ (0.1 A/m). Background energy flux densities did not exceed $0.27 \mu\text{W/cm}^2$. The measurements of the energy flux density were done with calibrated meter PZ-31 (Russian Federation). The maximum basic error of measurements did not exceed 2,7 dB.

5. Materials for manufacturing metal-polymeric material facing

To be applicable for facing large surfaces, the matrix material must be reasonably priced and easy-to-use. In addition, it must be mixed with the shielding filler and have sufficient strength and resistance to weathering. Such properties are typical for commonly used latex polymer. Latex-based material can be made both by adding a shielding substance during the latex production process [10] or into the ready-to-use liquid latex.

The iron ore concentrate obtained during its enrichment is selected as the screening substance. The average particle size of the concentrate is $150\text{-}200 \mu\text{m}$. The concentrate has the iron content (mainly in the form of magnetite) up to 82 %. The advantage of the iron ore is satisfactory electrical properties and low cost of the material. This enables its application in any concentration limited only by the mechanical properties of the final material.

6. Manufacturing technology of facing material for electromagnetic field shielding

At the initial stage, the iron ore concentrate was processed in a ball mill for one hour. Then, the particle-size analysis of the shielding substance was carried out by the sedimentation method, using torsion scales. It was necessary, because the shielding properties of metal polymers depend on the dispersion of metal and metal-containing particles [10]. For this purpose, the ratio between the relative amount of iron ore particles in the total mass of the filler ($-dQ/drQ_{\text{max}}$) and the particle sizes r was determined (Fig. 1).

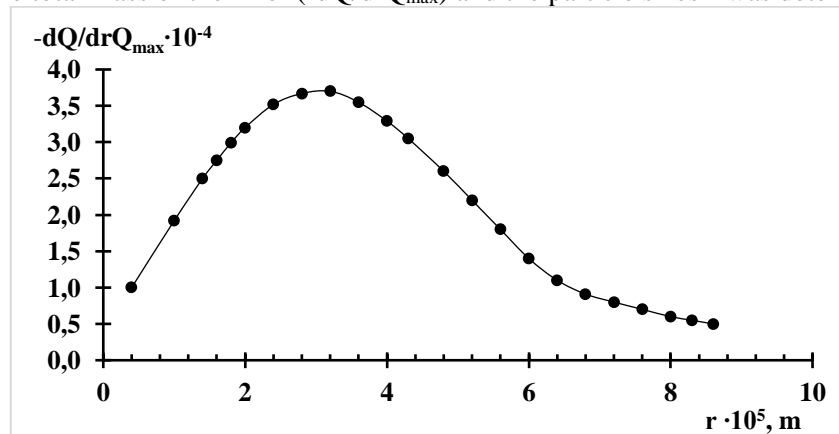


Figure 1. Distribution of the particles ($-dQ/drQ_{\text{max}}$) of iron ore concentrate by their size r

The data obtained indicate that the preferred fraction is particles of size 25-26 μm . This is important for the design of future shielding material with the desired shielding ratio of required or allowable thickness. It means that increasing the dispersion of the filler can reduce the thickness of the material. In the second step, the iron ore concentrate was added to the liquid latex in quantities of 5, 10, 15, 20 % (by weight). The resulting mixtures were thoroughly mixed in a special mixer and sonicated at the frequency of 23 kHz, with the amplitude of 45-50 μm for 10 minutes.

This treatment ensures a uniform distribution of the shielding particles in the latex and prevents them from sticking together. In order to obtain the final material, the metal-polymer mixture was squeezed on the rollers through the rectangular opening. The mixture was thermally treated between the rollers and the surface vulcanization was conducted there as well. The distance between the rollers was 5, 10, and 15 mm, which corresponds to the final thicknesses of the materials. The thickness of the vulcanized layer is 1.0-1.5 mm.

7. The study of the protective properties of facing materials for shielding electromagnetic fields

Testing of the protective properties of materials (shielding coefficients) was carried out in two stages. At the first stage, the shielding coefficients of the ultra-high frequency electromagnetic field and the contribution of electromagnetic waves reflection to the protective properties of materials were determined. The reflection measuring is necessary as the reflection of waves under real conditions can occur in undesirable directions and worsen the electromagnetic environment status both indoors and outdoors. Table 1 demonstrates the dependence of the shielding factor K_s on the content of the screening substance ρ , % (by weight) and the thickness of the screen. The energy flux density of the electromagnetic field source was 1300-1350 $\mu\text{W}/\text{cm}^2$.

Table 1. The dependence of the shielding factor of metal-polymer facing material on its thickness and the content of the shielding substance.

ρ , %	K_s		
	5 mm	10 mm	15 mm
5	3.2	7.4	12.3
10	6,8	14.5	33,4
15	22,0	48,2	92,2
20	34.5	77,2	125,5

It is well know, that the reflection coefficients do not depend on the thickness of the material, but are determined only by the electrophysical properties of its surface layer. Therefore, these values were measured for materials of the same thickness with various content of the screening substance. First of all, the simulations were performed by placing the antenna in the space between the source and the metal sheet with the opening, then - with the overlap of the opening by the screen and its absence (Table 2).

Table 2. The dependence of the electromagnetic waves reflection coefficients (K_r) of the facing material on the content of the shielding substance.

ρ , %	5	10	15	20
K_r	0.08	0.12	0.34	0.42

At the second stage, the shielding coefficients for the industrial frequency magnetic field were investigated (Table 3). The induction of the magnetic field source of the industrial frequency was 490-495 μT .

The results obtained indicate that the facing material developed is effective for shielding the ultra-low frequency magnetic field and the ultra-high frequency electromagnetic field. The shielding coefficients of the electrical component of the industrial frequency electromagnetic field were not

determined. This is because the shielding of the electric field is not a problem for any conductive material. In addition, it is believed that the magnetic field is more harmful to biological objects.

Table 3. The dependence of the shielding factor of the facing materials for the magnetic field of the industrial frequency on the content of the shielding substance.

ρ , %	Ks			
	5 mm	10 mm	15 mm	20 mm
5	1,2	2,4	3,3	5,5
10	3,4	5,8	7,2	11,7
15	13,6	22,4	32,2	44,2
20	34,5	20,5	49,6	98,4

8. Results and Discussions

The analysis of the testing results of the developed facing materials shows that they are efficient when used for shielding electromagnetic fields of ultra-low frequencies and electromagnetic fields of ultra-high frequencies. It is known that, even under production working conditions, magnetic fields of industrial frequency do not exceed the maximum permissible levels more than 2-3 times. Therefore, the proposed material has protective properties suitable for wide application. According to national and international standards the permissible values for ultra-high frequency electromagnetic fields are $10 \mu\text{W}/\text{cm}^2$. That is, even thin screen with low content of the screening substance will ensure the regulatory conditions or people staying inside the premises. The results give possibility to optimize shielding of premises and buildings accounting the priority of the impact factor on the environment. The obtained results show that the shielding coefficients of magnetic and electromagnetic fields significantly increase at concentrations of shielding particles over 10 %. Simultaneously, the reflection coefficient of electromagnetic waves also grows. This can only be explained by the manifestation of the percolation effect (a sharp increase in the electrical conductivity of the material). With this concentration of conductive particles, the conductivity threshold is reached due to the contact between the particles and the formation of conductive chains.

This fact can be used to design materials with the required protective properties. The change in the real dielectric constant of the material is the evidence of reaching the threshold of electric current flow. On this basis, it is possible to calculate the volume fraction of the ferromagnetic filler in the total volume of the protective material. For the calculations of dielectric conductivity ε , the Odelevsky formula was applied, it determines the dependence of the real dielectric constant on the dimensions of the filler particles, their bulk concentration and the dielectric characteristics of the matrix components:

$$\varepsilon = \varepsilon_m \left[1 + \frac{k(\varepsilon_f - \varepsilon_m)}{(1 - k/v) \cdot F(\varepsilon_f - \varepsilon_m) + \varepsilon_m} \right]$$

where ε_m is the dielectric constant of the matrix; ε_f – dielectric constant of the filler; k – volumetric concentration of the filler; v – critical concentration of the filler above which the particles are in contact with each other; F – depolarization index.

In turn, the depolarization factor can be obtained as

$$F = \frac{\ln(2l/d) - 1}{(1/d)^2},$$

where l is the length of the particle; d is the particle diameter.

From reference sources it is known that the relative dielectric constant of latex is 3.5-4.5. The main component of the mineral concentrate is magnetite, whose dielectric constant is 13.9-14.3. The

geometric parameters of the screening particles of medium or mean dispersion are easily determined by the metallographic method. This method enables prediction of the protective properties depending on the parameters of the field that require shielding. The shielding coefficients of the developed facing materials make them usable not only for protection of people from electromagnetic influences. They are suitable for solving the problems of electromagnetic compatibility of electronic and electrical equipment and technical protection of information. It is important to determine the possibility of increasing the efficiency of the developed protective materials. This was carried out through the metallographic research. The surface of the material and its cross-section (the inner part of the section) were investigated.



Figure 2. Structure of metal-polymer material with the content of shielding substance of 15 %:
a) material surface ($\times 150$), b) material cross-section surface ($\times 250$)

As it is seen in Fig. 2a) the distribution of the shielding particles on the surface of the material is uneven. It is most likely that this structure is formed because the rollers are not completely smooth. This has partially redistributed the fine iron ore concentrate. Fig. 2 b) indicates that the shielding particles are not evenly distributed in the inner part of the material and differ significantly in size. Preventing the redistribution of the shielding substance could be probably prevented by improving the quality of the rolling surface and their even heating. Increasing the dispersion and uniformity of the shielding filler distribution in the polymer body is possible by increasing the time and intensity of ultrasonic treatment of the original mixture. Thus, the ways to improve the developed materials are to increase the dispersion of the ferromagnetic filler and provide uniform distribution of the shielding particles in the body of the polymer material.

9. Conclusions

The developed latex-based material with fine ore concentrate filler material has small thickness, weight and cost with sufficient protective properties for domestic and industrial application.

The shielding coefficients of the electromagnetic fields of ultra-high frequencies (2.4-2.6 GHz) are 3.2-125.4 for the material 5-20 mm thick, containing 5-20 % shielding particles (by weight). The reflection coefficients are 0.28-0.42. Industrial frequency magnetic field shielding factors are 1.2-98.4.

The significant increase in the shielding coefficients at the concentrations of the shielding substance above 10% indicates the manifestation of percolation effect - the transition of the material conductivity threshold, which leads to the increase in the reflection coefficients of electromagnetic waves. The above presented calculation of the shielding substance critical concentration allows predicting the protective properties of the material, based on the electrophysical characteristics of the polymer matrix and the material of the shielding substance.

Improvement of the developed material is possible by increasing the dispersion of the shielding substance and the uniform distribution of the shielding particles in the polymer matrix. This will reduce

the weight and thickness of the facing material and reduce its cost while maintaining its protective properties.

References

- [1] Gonza'lez M, Pozuelo J, and Baselga J 2018 Electromagnetic Shielding Materials in the GHz Range. *The Chemical Society of Japan and Wiley VCH Verlag GmbH and Co. KGaA Weinheim Wiley Online Library*; Scheme. Rec. Vol **18** pp 1-11.
- [2] Kargar F, Barani Z, Balinskiy M G, Magana A S, Lewis J S and Balandin A A 2018 Graphene Composites with Dual Functionality: *Electromagnetic Shielding and Thermal Management* URL: <https://onlinelibrary.wiley.com/doi/full/10.1002/aelm.201800558>
- [3] Singh J 2015 Computer Generated Energy Effects on Users and Shielding Interference *International Journal of Innovative Research in Computer and Communication Engineering* Vol **3** Issue 10 pp 10022–10027
- [4] Mondal S, Ganguly S, Das P, Khastgir D and Das N C 2017 Low percolation threshold and electromagnetic shielding effectiveness of nano structured carbon based ethylene methyl acrylate nanocomposites *Composites Part B: Engineering* **119** pp 41–56 <https://doi.org/10.1016/j.compositesb.2017.03.022>
- [5] Yadav, Kuřitka, Vilčáková, Mac Hovský, Škoda, Urbánek et al 2019 Polypropylene Nanocomposite Filled with Spinel Ferrite NiFe₂O₄ Nanoparticles and In Situ Thermally Reduced Graphene Oxide for Electromagnetic Interference Shielding Application *Nanomaterials* **9** (4) p 621. <https://doi.org/10.3390/nano9040621>
- [6] Belyaev A A, Bepalov E E, Lepeshkin V V 2015 Radar absorbing materials based on finishing materials for protection from microwave radiation of base stations of cellular communications *Proceedings of VIAM* No **6** pp 1-9 <https://cyberleninka.ru/article/n/radiopogloschayuschie-materialy-na-osnove-otdelochnykh-stroitelnykh-materialov-dlya-zaschity-ot-svch-izlucheniya-bazovykh-stantsiy/viewer>
- [7] Jiao Y, Wan C, Zhang W, Bao W and Li J 2019 Carbon Fibers Encapsulated with Nano-Copper: A CoreShell Structured Composite for Antibacterial and Electromagnetic Interference Shielding Applications *Nanomaterials* **9** (3) p 460 <https://doi.org/10.3390/nano9030460>
- [8] Glyva V, Barabash O, Kasatkina N, Katsman M, Levchenko L, Tykhenko O, Nikolaiev K, Panova O, Khalmuradov B and Khodakovskyy O 2020 Studying the shielding of an electromagnetic field by a textile material containing ferromagnetic nanostructures *Eastern-European Journal of Enterprise Technologies* Vol **1** No 10 (103) pp 26-31 <https://doi.org/10.15587/1729-4061.2020.195232>
- [9] Lynkov L M and Byush V A 2019 New technologies for creating screens for electromagnetic radiation based on modified powder, nanostructured materials. *Reports of BSUIR* **2** pp 85-99
- [10] Glyva V, Lyashok J, Matvieieva I, Frolov V, Levchenko L, Tykhenko O, Panova O, Khodakovskyy O, Khalmuradov B and Nikolaiev K 2018 Development and investigation of protective properties of the electromagnetic and soundproofing screen *Eastern-European Journal of Enterprise Technologies* Issue 6/5 (**96**) pp 54–61 <https://doi.org/10.15587/1729-4061.2018.150778>.