1.7. COMPOSITE MATERIALS FOR SUSTAINABLE DEVELOPMENT AND ELECTROMAGNETIC SAFETY OF BIOLOGICAL AND TECHNICAL OBJECTS

Introduction. The scientific and technical progress intensive development in the last third of the 20th century increase the electromagnetic and electric energy use. Thanks for it new type of environmental pollution has appeared and formatted - it is electromagnetic pollution. In recent years, new electromagnetic pollution sources have been added to the natural electromagnetic Earth's background. They are cellular communication, radio communication antennas, remote monitoring and control equipment, household appliances, medical radio equipment and other equipment that generates electromagnetic energy in the environment.[92]

Electromagnetic radiation (EMR) includes electric, magnetic and electromagnetic influences characterized by frequencies and intensity of wide range and impact degree. All EMR sources are divided by origin into two large groups: natural and anthropogenic (technogenic). Natural ones include the Earth's field and radio waves generated by space objects (the sun, comets, galaxies, etc.). Anthropogenic include various industrial technological installations, household and office electronic equipment, gadgets, as well as other technical devices and equipments. Most of the anthropogenic sources surrounding people emit energy in the ultra-high frequency (UHF) range (300 MHz ... 300 GHz).[93] Natural electromagnetic field and anthropogenic one interaction increase electromagnetic pollution impact on people and ecosystems. According to Yu. G. Grigorieva: "the human body carries out its vital activities through a number of complex processes and mechanisms, including the use of intra- and extracellular electromagnetic interactions. The human body emits electromagnetic fields with a frequency higher than 300 GHz with an energy flow density of about 0.003 W/m^2, the electromagnetic habitat is actually a source of electromagnetic interference to human life and the ecosystem.[94] Thus, a contradiction arises between the role of the natural electromagnetic field as a factor in the life on Earth existence, and artificial electromagnetic pollution generated by man, which threatens both himself and other living organisms and plants.

The permissible level of EMR for different radio waves frequency ranges are given in Table 1. Since the electromagnetic radiation impact on a person depends on time, there are maximum permissible level of energy exposure (EE) for each parameters (Table 2).[95]

Table 1. Maximum permissible levels for EMR

Parameter	Maximum permissible levels in frequency ranges				
	30 kHz – 3 MHz	3 – 30 MHz	30,0 – 50,0 MHz	50,0 – 300 MHz	300 MHz – 300 GHz
Electric field strength (E), V/m	500	300	80	80	-
Magnetic field strength (H), A/m	50	-	3,0	-	-
Energy flux density (EFD), μW/cm^2	-	-	-	-	1000
Energy load (EL_{EFD}), μW·h/cm^2	-	-	-	-	200

In the general case, technical equipment, during their direct functions implementation, exert an electromagnetic impact on the environment, the same time they themselves are subject of electromagnetic interference impact generated by other sources, the spread of which occurs through antennas, wires and directly through electronic blocks frame. The EMR intensity impact in this case depends on the source capacity and the distance to it. Thus, another serious problem related to electromagnetic radiation appears – the problem of electromagnetic compatibility (EMC), which is currently one of the most important in electric power, both theoretically and in applied

[92] Almihat, M. G. M., Kahn, M. T. E., Aboalez, K., Almaktoof, A. M. (2022):Energy and Sustainable Development in Smart Cities: An Overview. Smart Cities, 2022, Vol. 5, 1389-1408.
[93] Budge, M. C. Jr., German, S. R. (2015): Basic Radar Analysis. Artech House, 2015, p. 45.
[94] McKinlay, A. F., Allen, S. G. et al. (2002): Review of the scientific evidence for limiting exposure to electromagnetic fields (0-300 GHz). Doc NRPB, 2004, Vol. 15, p. 12.
[95] Ibidem, p. 55.

terms. The importance of this problem is as great as the well-known problems of ecology, energy security and energy resource conservation. Non-compliance with EMC requirements can have quite serious consequences in various areas of human activity, starting from a decrease in technical devices functioning quality, ending with false activation and their failure[96].

Table 2. Maximum permissible level of energy exposure EE

Parameter	Maximum permissible level of energy exposure in frequency diapason				
	30 kHz – 3 MHz	3 – 30 MHz	30,0 – 50,0 MHz	50,0 – 300 MHz	300 MHz – 300 GHz
EE_E, $(V/m)^2 \cdot h$	2000	7000	800	800	-
EE_H, $(A/m)^2 \cdot h$	200	-	0,72	-	-
$EE_{ППЕ}$, $\mu W \cdot h/cm^2$	-	-	-	-	200

Thus, the literary sources analysis allows us to say that electromagnetic radiation is an inte gral part of human life, but at the same time an environmental risk factor that intensively pollutes the ecosystem. That is why, the problem how to protect biological and technical objects from the negative EMR impact is relevant and are of great scientific and practical interest.

There are various measures aimed at protecting biological and technical objects from EMR exposure, which can be divided into several types:[97]

- organizational, such as distance protection (location at the maximum allowable distance from the EMR area action); time protection (restriction staying in the EMR zone); quantity protection (the EMR sources capacity must be the minimum necessary);
- therapeutic and preventive – increasing the body's resistance to EMR exposure; sanitary and preventive provision; treatment in emergency situations;
- engineering and technical – special protective materials use; individual and collective protection use; structures improvement.

The greatest scientific and practical interest is engineering and technical measures. Design and creation special protective materials for shielding can help us. Two types of shielding are generally considered: shielding EMR sources from humans and shielding humans from EMR sources. The screens protective properties are based on the tension weakening effect and electric field distortion in the space near the grounded metal object. Protection against the industrial frequency magnetic field is possible only at the product development or object design stage. The field level reduction is achieved due to vector compensation, since other shielding the industrial frequency magnetic field methods are extremely complicated and expensive.[98] Various radio reflectors (RR) and radio absorbing materials are used for EMR shielding in radio frequency ranges. RR materials includes various metals – iron, steel, copper, brass, aluminum. To protect against UHF, thin or perforated sheets, conductive films, metallized fabrics or metal meshes are used, which have sufficient attenuation, but differ from sheet materials in lower weight and cost. The sources` analysis showed that today a wide range of materials have been designed that provide a high EMR shielding level and are designed to create flexible screens, protective clothing and covers to ensure biological protection and electromagnetic compatibility of radio-electronic equipment.[99] The RR materials disadvantages for human protection include "EMR reflection from curved surfaces of the protected object leads to interference of waves with different amplitudes and phases and, as a result, individual body parts irradiation".[100] This circumstance necessitates

[96] Ozen, M. S. E. Sancak, A. Beyit, I. Usta, M. Akalin (2012): Investigation of electromagnetic shielding properties of needlepunched nonwoven fabrics with stainless steel and polyester fiber. Textile Research Journal, 2012, p. 23-33.
[97] Drinovsky, J., Kejik Z. (2009): Electromagnetic shielding efficiency measurement of composite materials. MeasSciRev, 2009, Vol. 9, p. 109-112.
[98] Rajendrakumar, K. (2012): Electromagnetic shielding effectives of copper/PET composite yarn fabrics. Indian journal of fiber and textile research, 2012, Vol. 37, № 6, p. 133-137.
[99] Hua, Z., Jianchun, Z., Pïng, C. (2007): Investigation on the Radar Absorption Properties of Carbon Fiber Containing Nonwovens. Journal of Industrial Textiles, 2007, Vol. 37, № 1, p. 91-105.
[100] Tong, X. (2008): Advanced materials and design for electromagnetic interference shielding. CRC Press, Boca Raton: Engineering & Technology, 2008, p. 23.

the RR materials use to reduce the EMR impact. The radio-absorbing material provides a reduction in the overall EMR level reflection in the radio range due to the electromagnetic energy conversion. The reason for the EMR energy dissipation in its propagation in the material is the conduction, magnetization and polarization processes. From a technological point of view, radio-absorbing materials can be divided into two large groups. The first group is materials or radio-absorbing coatings (RAC), the second group is structural radio-absorbing materials (RAM). Most often, the initial components composition, the intended structure and the structural RAC and RAM purpose are equal.[101]

According to the operation principles, the representative class of designed RAC and RAM can be conditionally divided into next types:[102]

1) gradient materials, the outer layer of which has radiophysical properties as close as possible to the free space characteristics and the magnetic and dielectric permeability change values continuously in the direction of increase from the material surface layer to the depth;

2) materials, which action is based on "electrodynamic swamp" principle, the distinguishing feature of which is uniformity, that is, the radiophysical characteristics practically do not change in the direction from the material surface to the depth (cellular, fibrous and foam composites can be classified as such materials);

3) multiplanar, which are structures consisting of a large number of thin conductive or ferromagnetic films, separated by dielectric and interference-absorbing layers, which action is based on the full or partial mutual quenching the electromagnetic wave incident and reflected from the metal substrate.

Such materials, depending on the purpose, can be conventionally divided into rigid and flexible (elastic). The rigidity or flexibility degree will depend on the polymer matrix type and structure.[103] Rigid screens are used in the mobile screens construction to locate service personnel in repair places or to limit local UHF sources impact, to separate or shield individual elements or blocks inside radio technical devices. Flexible materials are used for the equipment covers and capes production as well as protective clothing for household and special purposes production. It is important that all materials, regardless of their composition and construction, are designed based on the specified requirements achievement. Specified requirements is defined by the frequency band within which the effective level of EMR absorption is achieved. Different RAM types are well-known, but their receiving often very difficult technological process with low productivity. Thus, in works,[104] RAM was received by the polymer melt extrusion method with structure fixation by cooling. A polyethylene terephthalate and polypropylene mixer modified by different conductive fillers was used as a polymer matrix.[105]

To provide IR radio-absorbing properties, it is necessary to introduce a dispersed conductive filler into its composition.[106] The main radiophysical characteristics value of a material with dispersed conductive phase is determined by the filler microstructure, particles size and its volume

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[101] Chen, L. F., Ong, C. K., Neo, C. P., Varadan, V. V., Varadan, V. K. (2004): Microwave Electronics: Measurement and Materials Characterization. John Wiley & Sons, Chichester, 2004, p. 33.

[102] Pozar, D. Microwave engineering. John Wiley & Sons, Hoboken, 2005, p. 40.

[103] Liu, Q. H., Xu, X. H., Xia, W. H., Che, R. C., Chen, C., Cao, Q., et al. (2015): Dependency of magnetic microwave absorption on surface architecture of $Co_{20}Ni_{80}$ hierarchical structures studied by electron holography. Nanoscale, 2015, Vol. 7, p. 1736-1743.

[104] Lv, H. L., Jia, G. B., Wang, M., Shang, C. M., Zhang, H. Q., Du, Y. W. (2014): Hexagonal-cone like of $Fe_{50}Co_{50}$ with broad frequency microwave absorption: effect of ultrasonic irradiation time. J Alloy Compd 2014; 615: 1037-1042.

Lisachuk, G., Kryvobok, R., Voloshchuk, V., Lapuzina, O., Zakharov, A. (2021): Study of Technological Features of Celsian Ceramics Creation. Proceedings of the 2021 IEEE 11th International Conference "Nanomaterials: Applications and Properties", NAP 2021.

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fraction in the polymer matrix.[107] Different geometric shapes and sizes particles are used as a conductive filler. The particles shape are: spherical (soot, metal powders, colloidal graphites, metallized microsclospheres), lamellar (expanded graphite, metal powders after attrition treatment, metallized mica) and needle-like (carbon fibers, metallized fibers, needles).[108] As a rule, composites filled with lamellar or needle-like particles have better radio-absorbing characteristics.[109] Conductive filler type choice is determined by the composite complex dielectric permeability that depending on conductive filler concentration. At the same time, the concentration, taking into account the dispersity of the filler, should be optimized not only for achieving the reduction reflection coefficient required level, but also taking into account the weight, size, physical-mechanical and technological limitations in the RAM production and application.[110]

From the works [111], it is obvious that RAM containing dispersed particles, with high radiophysical properties level, have a high specific gravity and low physical and mechanical properties. The fibrous fillers with different lengths and diameters introduction into the polymer matrix makes it possible to expand the absorption range and increase the RAM reflection coefficient without worsening other operational properties.[112]

An important problem in the RAM design is to ensure electromagnetic compatibility of radio-electronic devices, medical equipment and other equipment related to EMR generation, as well as special clothing for human protection made. Such materials should have such properties: an effective radio absorption level, flexibility, light weight, manufacturability and low cost, which are primarily determined by operating conditions and protection object type.[113] Designing RAMs, that are effective in UHF – because most household and industrial electromagnetic radiation sources are operated in this diapason – is of great practical interest.

The aim of the work is science-based technological solutions finding for receiving composite radio-absorbing materials with high electrophysical properties for the designing new objects to protect people and other biological spices and technical equipment from the EMR impact.

The objects of study were:

- Durethane polyamide 6 (Bayer, Germany);
- silicon carbide SiC.

Polymer composite materials were obtained by extruding pre-prepared raw materials in a single-screw laboratory extruder at a temperature of 170-200°C and a roll rotation speed of 30-100 rpm.

The study of impact strength and breaking stress during bending of the samples of composite materials, without notching at a temperature 20°C, was carried out on a pendulum head according to ISO 180 and ISO 178, respectively.

The composite materials density is calculated according to the formula:

$$\rho = m\,\rho_0/\{m-(m_1-m_2)\},$$

[107] Lebedev, V., Kryvobok, R., Cherkashina, A., Bliznyuk, A., Lisachuk, G., Tykhomyrova, T. (2022): Design and Research Polymer Composites for Absorption of Electromagnetic Radiation. 2022 IEEE 3rd KhPI Week on Advanced Technology (KhPIWeek), 2022, p. 1-4.

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[110] Hu, J. T., Zhao, T. K., Peng, X. R., Yang, W. B., Ji, X. L., Li, T. H. (2018): Growth of coiled amorphous carbon nanotube array forest and its electromagnetic wave absorbing properties. Compos Part B-Eng, 2018, Vol. 134, p. 91-97.

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where m – sample's mass in air, g;
m_1 – the sample's mass with the wire in water, g;
m_2 –wire's mass immersed in water or alcohol, g;
ρ_o – water or alcohol density at 20 ºC.

The melt flow index (MFI) study of polymer composites was performed using the IIRT-M device at 270°C and a load of 2.16 kg.

The measurement of the sample for transmission coefficient T (transmission T) and standing wave ratio (SWR) was carried out on an automated scalar spectrum analyzer P2-65 in the frequency range of 26-37.5 GHz. The spectrum was digitized and displayed on the computer screen using the National Instruments LabVIEW program. The sample completely filled the waveguide cross-section of 7.2 x 3.4 mm^2.

Results discussion. Primary studies were aimed at studying the influence of silicon carbide particles the introduction on the polyamide 6 strength properties complex – Figure 1.

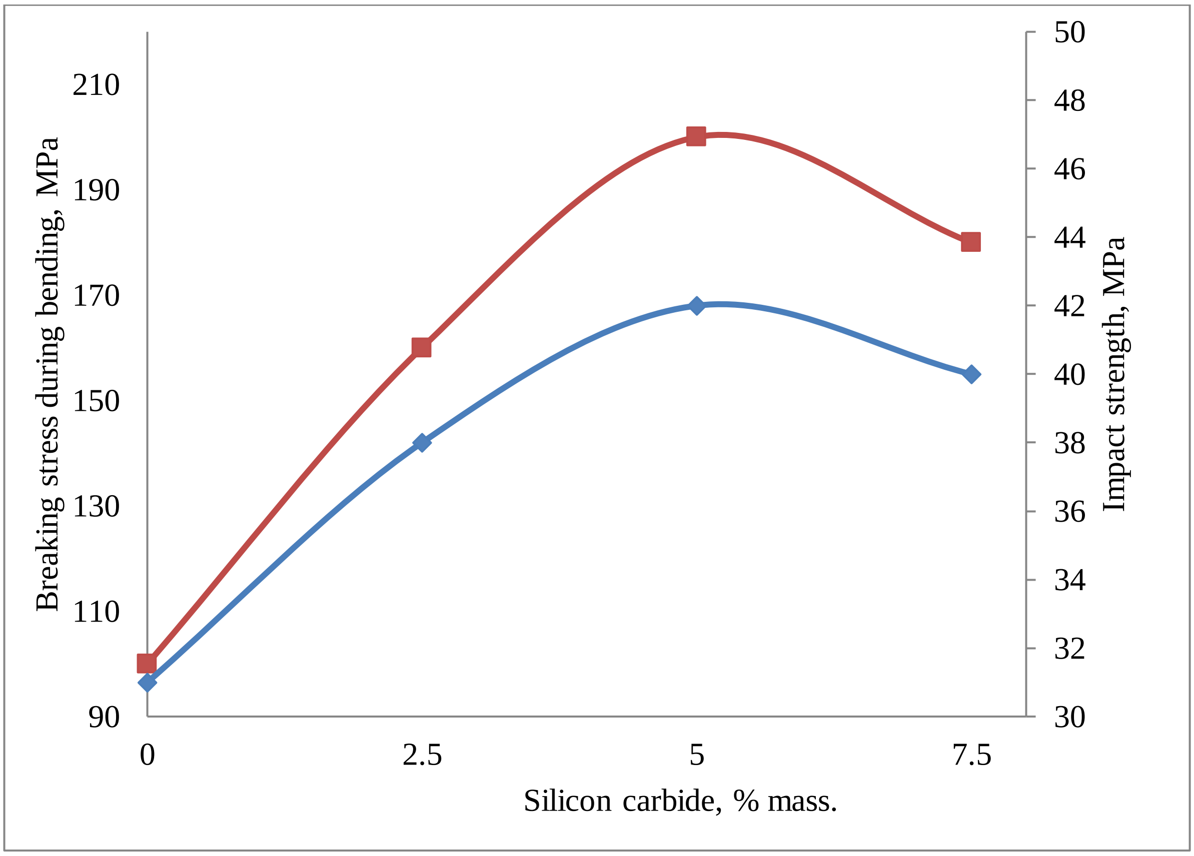

Fig. 1. Studying the influence of silicon carbide particles the introduction on the polyamide 6 strength properties complex

From the results shown in figure 1 it is seen that the modification of polyamide 6 with silicon carbide allows to obtain high-strength composite materials, while the optimal content of silicon carbide over 0.5% by mass.

Secondary studies were directed to the silicon carbide particles introduction impact on technological properties of polyamide 6 (Table 3).

Table 3. Study of silicon carbide particles introduction impact on polyamide 6 technological properties

Silicon carbide, % wt.	Melting temperature, ºC	Density, g/sm^3	MFI, r/10 min.
0	216	1130	22
2.5	217	1145	21.5
5.0	218	1165	21
7.5	219	1170	20.5

From in Table 3 we can see, that polyamide 6 modifications with silicon carbide is accompanied by an increase in the heating temperature from 216 to 219ºC, density from 1170 to 1210 g/cm^3, and a decrease in MFI from 22 to 20.5 g/10 min.

The spectrum transmission coefficient T of polymer composites based on polyamide 6 and 5% wt. silicon carbide, which is relatively the same throughout the frequency range is shown on Fig. 2.

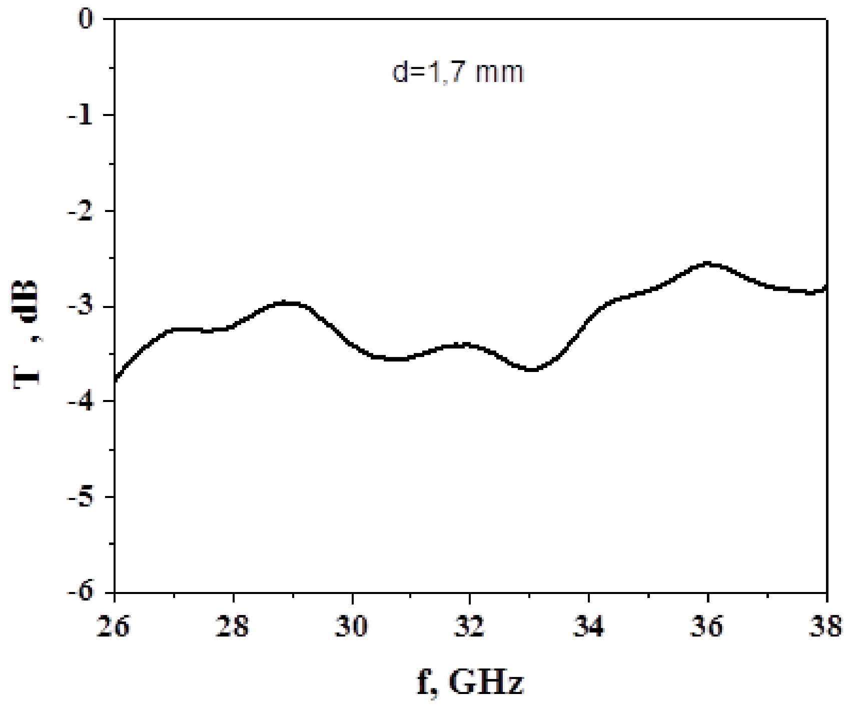

Fig. 2. Spectrum transmission coefficient T of polymer composites based on polyamide 6 and 5% mass silicon carbide

The spectral dependence of the standing wave ratio on the SWR voltage of polymer composites based on polyamide 6 and 5% mass silicon carbide is shown on Fig. 3.

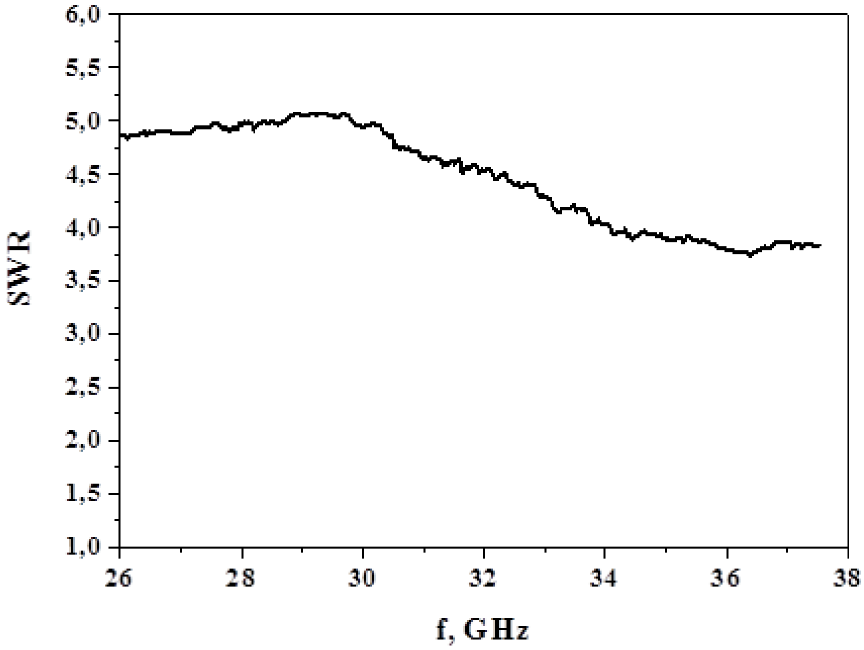

Fig. 3. Spectral dependence of the standing wave ratio on the SWR voltage of polymer composites based on polyamide 6 and 5% mass silicon carbide

The value of the calculated reflection coefficient Γ and absorption coefficient A of polymer composites based on polyamide 6 and 5% mass silicon carbide is shown in Fig. 4-5.

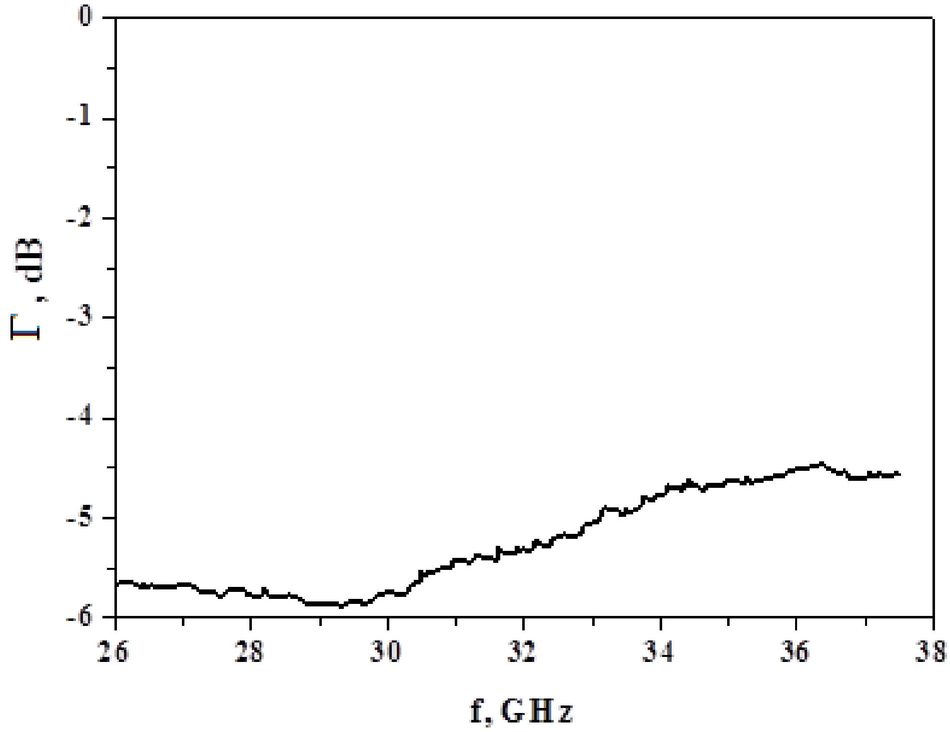

Fig. 4. Spectral dependence of the calculated reflection coefficient Γ of polymer composites based on polyamide 6 and 5% mass silicon carbide

As a result of experimental data, it can be concluded that polymer composites based on polyamide 6 and 5% wt. silicon carbide are relatively transparent in the millimeter frequency range (about 3 dB, this is a 2-fold attenuation), which have a small value of the absorption coefficient.

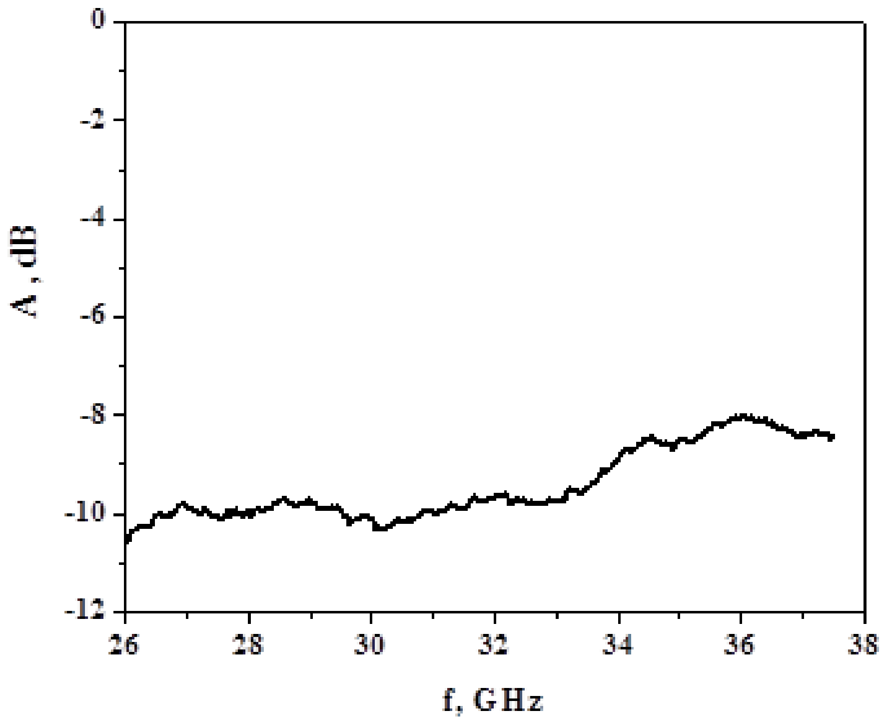

Fig. 5. Spectral dependence of the calculated absorption coefficient A of polymer composites based on polyamide 6 and 5% mass silicon carbide

Conclusions. Thus, polymer composites for electromagnetic radiation absorption based on polyamide 6 and silicon carbide were received in this study. It is shown that the optimal concentration of silicon carbide in the designed polymer composites from looking for their strength characteristics is 5% mass It is shown that the spectrum transmission coefficient T of polymer composites is relatively the same in the entire frequency range, and the obtained SWR values indicate a rather large reflection coefficient Γ for the designed polymer composites.

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