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Ceramic-Ferromagnetic-Graphite Polymer Composites for Electromagnetic Radiation Absorbing

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Abstract

Electromagnetic absorbing composites modified by ceramic- ferromagnetic-graphite (CFG) fillers were first received. Ceramic- ferromagnetic-graphite polymer composites impact strength characteristics were researched and compositions with a higher silicon carbide SiC-10 % wt. content were studied, while chromium oxide Cr_2O_3 and graphite content in 5-15% wt. range was optimized. It is shown, that chromium oxide Cr_2O_3 and graphite introduction in polyamide 6-SiC 10 % wt. system increases their impact strength and breaking stress during bending. As a result of statistical data processing, the approximating curves equation were obtained, which allow to calculate ceramic- ferromagnetic-graphite polymer composites strength characteristics. It is shown that the nature of modification effect for CFG fillers on ceramic- ferromagnetic-graphite polymer composites complex spectral characteristics for absorbing electromagnetic radiation indicates the advantage in using complex system in order to receive effective materials.

Keywords: *Polymer; Ceramic; Ferromagnetic;, Graphite; Composites; Electromagnetic radiation; Absorbing materials; Strength properties; Spectral characteristics.*

1. Introduction

The widespread polymer composites using for absorbing electromagnetic radiation is associated with industry development and modern electronic pollution emergence [1–6]. The highly efficient materials development for electromagnetic radiation absorption with small thickness, low density, transmission and absorption wide range, which are of great interest for solving problems with electromagnetic radiation absorption, is underway [7-8].

In general, the action mechanism of modern materials for electromagnetic radiation absorption is related to the electromagnetic radiation dissipation falling on them at a minimum reflection level, which allows solving various functional tasks. This can be "parasitic" radiation absorption inside the high-frequency units in different devices or the military equipment radar visibility reduction. Depending on the frequency range, which is usually determined by electromagnetic waves reflection coefficient, materials for electromagnetic radiation absorption are divided into broadband and resonant. Electromagnetic energy absorption occurs due to dielectric and magnetic losses, conduction losses, which are tried to be maximized in order to achieve maximum shielding efficiency. Today, there is a wide variety of shielding materials and composites due to interrelated factors. First, it is a complex mechanism of electromagnetic waves propagation and electromagnetic radiation absorption. Secondly, there is technological difficulties in materials synthesis with predefined electromagnetic properties in frequencies wide range.

There are many types of materials that can be used to shield electromagnetic radiation [9-22]. The most common type of material is metal, which can be used in the form of foil, mesh or screen [11-13]. Other common materials include conductive polymers [9-10], composites [15-16] and ceramics [14]. Each type of material has its own advantages and disadvantages, so it is important to choose the right type of material for a specific application. Materials for protection against electromagnetic radiation based on metals [11] and ferromagnets [12], as a rule, are the most effective for blocking electromagnetic radiation, but they are the most expensive and technological difficult from a producing point of view. Conductive thermoplastic polymer materials are a good alternative to metal-based materials because they are more manufacturable and affordable, but they are not as effective in blocking electromagnetic radiation [17-19]. Composites and ceramics filled with silicon carbide [20], carbon fibers [21-22], carbon black [23], and carbon nanotubes [24-25] are two other options for high-performance shielding materials that strike a balance between manufacturability, affordability and efficiency. Thermoplastic composites based on polyamide, silicon carbide and potassium titanates yearly were received by us, but they have a small absorption coefficient [26-33]. So further research in the framework of the composites with complex CFG fillers application is perspective.

2. Material and methods

2.1. Object of study

The aim of the article is to study polymer ceramic-ferromagnetic-graphite composites for electromagnetic radiation absorbing. The tasks of the article are:

– to investigate CFG fillers impact on strength characteristics of polyamide-based polymer composites;

– determine the electromagnetic absorption characteristics by polymer composites based on polyamide and CFG fillers.

2.2. Materials

To receive polymer ceramic-ferromagnetic-graphite composites were used: polyamide 6 TM Durethane (Bayer, Germany); silicon carbide SiC powder (particles size 50–65 μm, specific volume resistivity, melting temperature 2700°C and coefficient of linear thermal expansion, α, between 5.10^6 and 7.10^6, K^{-1}); chromium oxide powder Cr_2O_3 (particle size 2–5 μm, melting temperature 2435° C, boiling temperature near 4000°C); graphite powder (particle size 20–25 μm), which was received from standard graphite workpiece (Fig. 1a).

Fig. 1 Photographs of laboratory research: a – graphite workpieces

b – roller crusher

Fig. 1 Photographs of laboratory research: c – cylindrical mill on elastic suspensions; d – mechanical scatterer.

Graphite workpieces were crushed to a class of less than 0.2 mm using a roller crusher (Fig. 1, b). Analytical moisture, ash content, hydrogen and carbon parameters were determined in the received graphite sample (Table 1) according to the existing regulatory documentation: ISO 589:2015, DSTU 8995:2020, ISO 1171:2010, ISO 625:1996.

Next graphite sample was further crushed to 100% content of the grade less than 0.075 mm using a cylindrical mill (Fig. 1, c) on scatterer (Fig. 1, d) on 0.02 mm sieves (Table 2).

Polymer ceramic-ferromagnetic-graphite composites were received on single-screw laboratory at 170–200°C and a screw speed 30–100 rpm.

Table 1.Quality indicators of carbon graphite sample.

№	Indicator	Symbol, unit of measurement	Value
1	Total moister	W^r_t, %	0,10
2	Analytical moisture	W^a, %	0,10
3	Ash content	A^d, %	0,18
4	Carbon content	C^d, %	99,06
5	Hydrogen content	H^d, %	0,76

Table 2. Graphite sieve analysis results

Class, mm	Value, %
< 0,02	31,4–43,2
0,02–0,075	56,8–68,6

2.3. Research methods

Impact strength and breaking stress during bending determination was carried out according to ISO 180 and ISO 178, respectively. Spectral characteristics was performed on a scalar spectrum analyzer P2–65 in automatic mode in the frequency range 26–37.5 GHz.

LabVIEW (National Instruments) were used to digitize the spectra via a computer. The examined samples size satisfied the requirements for the waveguide cross-section complete filling (7.2x3.4 mm^2) with a sample thickness 5 mm. The transmission coefficient T and the voltage standing wave ratio (SWR (Standing wave ratio)) were determined in the samples.

3. Results of ceramic-ferromagnetic-graphite polymer composites development

Primary studies were directed at studying the introduction impact of silicon carbide SiC, chromium oxide Cr_2O_3 and graphite on the polyamide 6 compositions strength properties. From previous works [26,28] it was established that increasing the silicon carbide SiC content in polyamide 6 led to an increase in both impact strength and breaking stress during bending (flexural strength). Looking for this characteristics optimal filler content is 5% wt. received compositions doesn't have sufficient electromagnetic radiation absorption properties. Compositions with a higher silicon carbide SiC - 10 % wt. content and optimized the chromium oxide (Cr_2O_3) and graphite content in 5–15 % wt. range are researched in this article . Also, to establish the synergistic effect while using three different CFG fillers, polyamide 6 – SiC – Cr_2O_3 – graphite systems were researched. In the fig.2 presents data on fillers degree impact for ceramic-ferromagnetic-graphite polymer composites based on the polyamide 6 – SiC – Cr_2O_3 – graphite system on impact strength and breaking stress during bending (flexural strength). Data from Fig. 2 shows that chromium oxide Cr_2O_3 and graphite introduction in polyamide 6 - SiC 10 % wt. system increases their impact strength and breaking stress during bending.

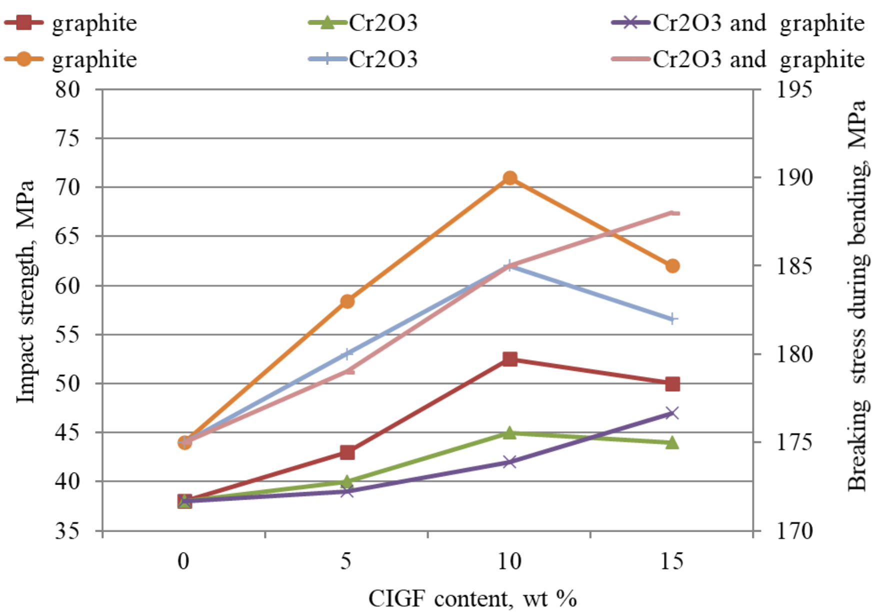

Fig 2. Fillers degree impact on impact strength and breaking stress during bending of polymer ceramic - inorganic composite based on polyamide 6 – SiC 10 wt %– Cr_2O_3 5-15 wt %– graphite 5-15 wt %.

A statistical data processing resulted in building approximating curves equations, which allow to calculate the impact strength *a* (MPa) and breaking stress during bending *σ* (MPa) value depending on graphite and chromium oxide content:

$$a = 37{,}7279 + 1{,}5348 \cdot x + 0{,}4927 \cdot y - 0{,}0414 \cdot x^2 - 0{,}0756 \cdot x \cdot y - 0{,}0004 \cdot y^2 \quad (1)$$

$$\sigma = 174{,}8137 + 2{,}3214 \cdot x + 1{,}3845 \cdot y - 0{,}105 \cdot x^2 - 0{,}0827 \cdot x \cdot y - 0{,}0566 \cdot y^2 \quad (2)$$

where x – graphite content, wt %; y – Cr_2O_3 content , wt %.

Equations 1 and 2 allows to simulate impact strength (Fig. 3) and breaking stress during bending (Fig. 4) values while fillers (graphite and Cr_2O_3) content from 0 to 15%.

Fig. 2-4 analysis shows that the strength characteristics maximum level is typical for polyamide 6 - SiC 10 % wt.– graphite 10 % wt. systems. As a result of statistical data processing, the approximating curves equation were obtained, which allow to calculate ceramic-ferromagnetic-graphite polymer composites impact strength and breaking stress during bending. Such results indicate the advantage of using a triplex fillers system - SiC 10 % wt.– Cr_2O_3 10 % wt.– graphite 10 % wt. in order to receive effective materials with high strength characteristics.

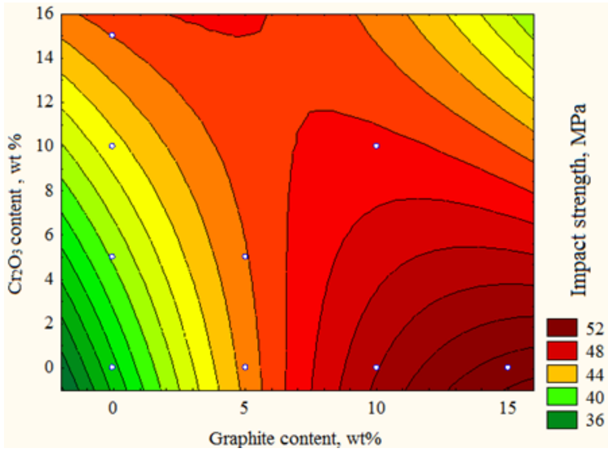

Fig. 3. 2D-model projection of impact strength (MPa) depends from graphite and Cr_2O_3 content , % wt in polymer composition based on polyamid 6 with 10 % wt. SiC.

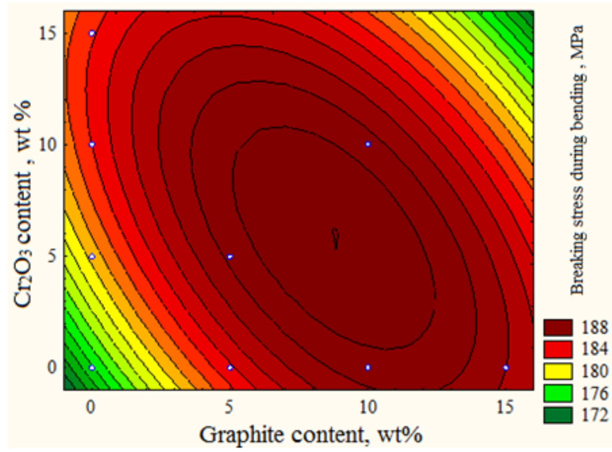

Fig. 4 2D-model projection of breaking stress during bending (MPa) depends from graphite and Cr_2O_3 content , % wt in polymer composition based on polyamid 6 with 10 % wt. SiC.

4. Results and discussion of spectral characteristics of ceramic-ferromagnetic-graphite polymer composites

For ceramic-ferromagnetic-graphite polymer composites with optimal strength characteristics researches of their electromagnetic radiation absorption characteristics on an automated scalar spectrum analyzer P2–65 in the frequency range 26–37.5 GHz. It was established that with Cr_2O_3 and graphite addition, an increase in the reflection coefficient Γ is observed (Fig. 4).

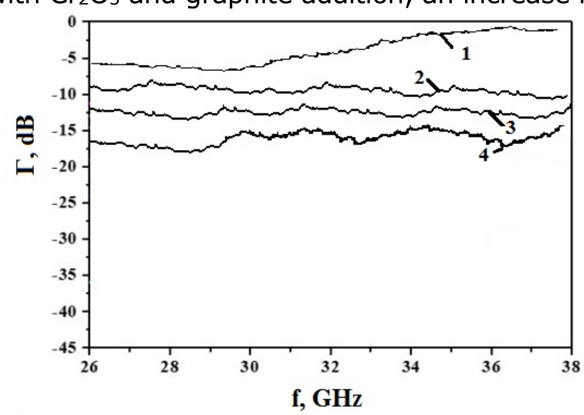

Fig. 4. Spectral dependence of the calculated reflection coefficient Γ for electromagnetic radiation absorption polymer ceramic-inorganic composites: 1 – polyamide 6 – SiC 10 wt%.; 2 – polyamide 6 – SiC 10 wt%– Cr_2O_3 10 wt%; 3 – polyamide 6 – SiC 10 wt%– graphite 10 wt%.; 4 – polyamide 6 – SiC 10 wt%– $Cr_2O_3$10 wt%.– graphite 10 wt%.

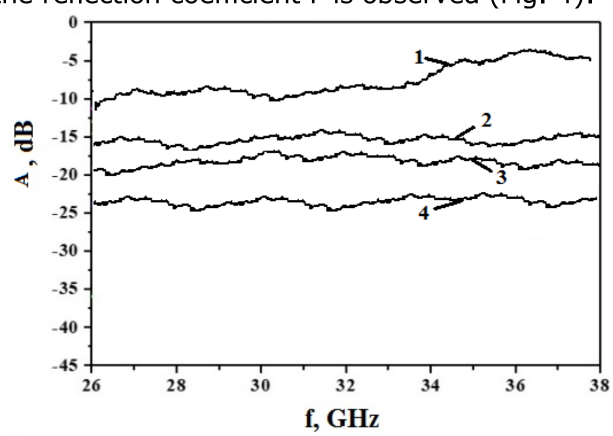

Fig 5. Spectral dependence of the calculated absorption coefficient A for electromagnetic radiation absorption polymer ceramic-inorganic composites: 1 – polyamide 6 – SiC 10 wt%.; 2 – polyamide 6 – SiC 10 wt%– Cr_2O_3 10 wt %; 3 – polyamide 6 – SiC 10 wt%– graphite 10 wt%; 4 – polyamide 6 – SiC 10 wt%– Cr_2O_3 10 wt%.– graphite 10 wt%.

The reflection coefficient Γ on SWR dependence we have used next formula:

$$\Gamma = \frac{SWR - 1}{SWR + 1} \qquad (3)$$

The reflection coefficient highest level is typical for polyamide 6 - 10 % wt. silicon carbide - 10 % wt.Cr_2O_3 - 10 % wt. graphite, which is related to the complex nature of CFG fillers action. Next, the electromagnetic radiation absorption efficiency of received polymeric ceramic-inorganic-graphite composites was determined. To do this, we determined the absorption coefficient A (Fig. 5), which was calculated according to the formula:

$$A=1-\Gamma-T \qquad (4)$$

An increase in the reflection coefficient Γ is observed when chromium oxide Cr_2O_3 and graphite are added to the systems - polyamide 6 - SiC 10 % wt. (Fig. 5) At the same time, the Γ highest level was typical for polyamide 6 – SiC 10 % wt.– Cr_2O_3 10 % wt.– graphite 10 % wt. Such results indicate the advantage of using a triplex fillers system - SiC 10 % wt.– Cr_2O_3 10 % wt.– graphite 10 % wt. in order to receive effective materials for electromagnetic radiation absorption.

5. Conclusions

Electromagnetic radiation absorbing composites modified by ceramic-ferromagnetic-graphite fillers were first received. Ceramic-ferromagnetic-graphite polymer composites impact strength and breaking stress during bending were researched and compositions with a higher silicon carbide SiC - 10 % wt. content were studied, while chromium oxide Cr_2O_3 and graphite content in 5-15% wt. range was optimized. It is shown, that chromium oxide Cr_2O_3 and graphite introduction in polyamide 6 - SiC 10 % wt. system increases their impact strength and breaking stress during bending. As a result of statistical data processing, the approximating curves equation were obtained, which allow to calculate ceramic-ferromagnetic-graphite polymer composites impact strength and breaking stress during bending.

It is shown that the nature of the effect of the modification of ceramic-ferromagnetic-graphite fillers on the complex of spectral characteristics of the studied indicates The ceramic-ferromagnetic-graphite fillers complex system using advantage is proven by studying the nature of modification effect on ceramic-ferromagnetic-graphite polymer composites for electromagnetic radiation absorption by CFG fillers. For polyamide 6 the triplex modification system consist on SiC 10 % wt. – Cr_2O_3 10 % wt. – graphite 10 % wt. and ensures the complex impact on composites characteristics from CFG fillers.

Symbols

W^a	*moisture contents, %;*
W^r_t	*total moisture, %;*
A^d	*ash content, %;*
C^d	*content of carbon, %;*
H^d	*content of hydrogen, %;*
a	*impact strength, MPa;*
σ	*breaking stress during bending;*
A	*absorption coefficient, %;*
Γ	*reflection coefficient, %;*
T	*transmission coefficient, %;*
SWR	*voltage standing wave ratio.*

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