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New magnetic composite materials for electromagnetic shields at microwave frequencies

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In this paper we report the preparation and the microwave properties of magnetic composite materials for electromagnetic shields.These materials contain a ferromagnetic composite in proportion of 60-99%. By heat treatment in air or reducing atmosphere takes place the phase transformation of Fe_2O_3 into Fe_3O_4, γ Fe_2O_3 and Fe metallic. The magnetic shields were obtained by mixing with Ba M-type ferrite, and continued with the compacting with a powdered epoxy-acrylic resin composition, at a ratio of 1-3 mass %. Another set of samples was obtained by mixing with the rubber (at a ratio of 20-40 mass %).

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1. Introduction

Recently, a series of studies has been conducted into possible health effects of exposure to no ionizing electromagnetic field [1,2]. Unionizing electromagnetic fields are produced by devices involved in the generation, distribution or use of electromagnetic waves. On the other hand insufficient research has been conducted to protect the people of non-ionizing electromagnetic fields produced by mobile telephones, telecommunication transmitter, microwave ovens, radars, diathermy units etc. Carbonyl iron loaded rubber is often used to achieve the absorbers, which has, however, narrowed bandwidth. The bandwidth of Ba M-type ferrites is still too small(<1 GHz) and needs to be expanded.

The aim of this study is the research of new magnetic composite materials for broadband electromagnetic wave absorbers and shields and the characterization of shields at microwave frequencies of 0.8-12 GHz.

2. Experimental procedure

The magnetic composites have been obtained by processing of the chemical offal from Chemical Industry [3]. By heat treatment in air or reducing atmosphere take place the phase transformation of Fe_2O_3 into Fe_3O_4, γ Fe_2O_3 and Fe metallic. X-ray diffraction and scanning electron microscopy were used to find detailed information on the crystallography and morphology of magnetite and iron formation as a function of processing technology. A correlation was established between magnetic hysteresis parameters and the observed crystal structure evolution. The samples of pyrites ashes calcined in reducing atmosphere show the best magnetic properties, the specific magnetization of 128 emu/g.

X-Ray Diffractometry (XRD) was used to find detailed information on the crystallography and morphology of ferromagnetic composite formation as a function of processing technology. The crystallographic evolution of magnetic composite with temperature and atmosphere is shown in Fig. 1.

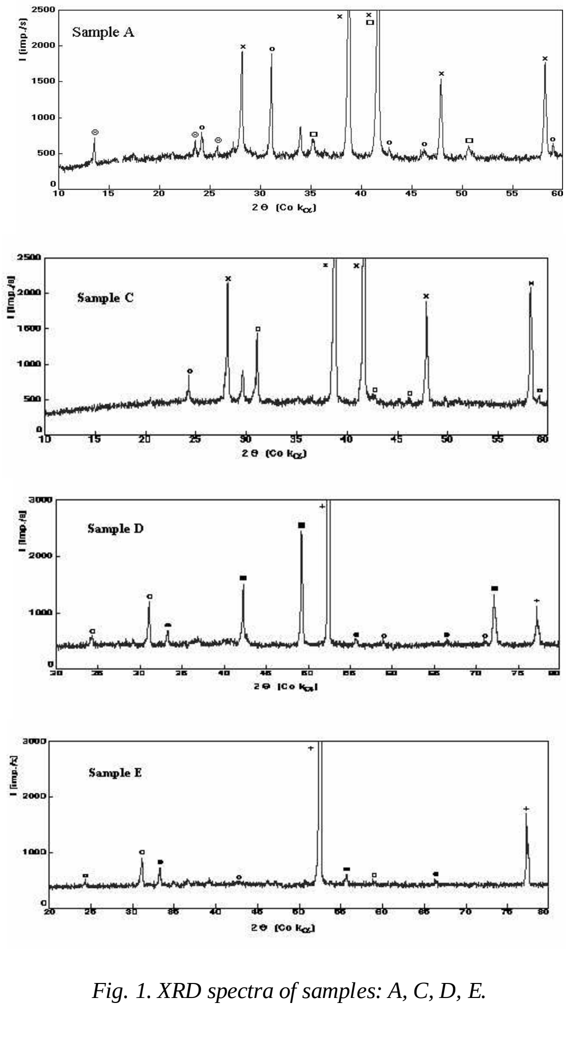

Fig. 1. XRD spectra of samples: A, C, D, E.

Table 1. XRD Crystallographic evolution with temperature and atmosphere of treatment.

Sample A/ offal	Sample C/ 800 °C/2h Oxygen atm.	Sample D/ 800 °C/2h reducing atm.	Sample E/ 850°C/2h. reducing atm.
x = α Fe_2O_3	x = α Fe_2O_3	+ = α Fe	+ = α Fe
◦ = SiO_2- quartz	◦ = SiO_2-quartz	▪ = FeO (cubic)	◦ = SiO_2- quartz
▫ = Fe_3O_4		◦ = SiO_2- quartz	• = FeS (cubic)
- = $Fe_4(OH)_{10}SO_4$uncertain		• = FeS (cubic)	

The magnetic composites and shields were obtained by mixing with Ba M-type ferrite and continued with the compacting with a powdered epoxy-acrylic resin composition, at a ratio of 1-3 mass %. Another set of samples was obtained by mixing with the rubber (at a ratio of 20-40 mass %).

The properties of attenuation at microwave frequencies have been determined between 0.8-11 GHz, by the method of the transmission line, using measuring set-up RAFENA-WERKE. The analysis is based on Schekunoff impedance concept.

3. Experimental setup

The experimental setup for determination of attenuation for shields at microwave frequencies (mw) is formed by spectrum analyzer, microwave generating antenna (circle) or conic antenna, antenna for receiver, and measuring receiver equipment (table 2).

Table 2. Equipments for determination of MW attenuation.

	Apparatus	Type of apparatus	Frequencies
1	Spectrum analyzer TAKEDA-RIKEN	TR-4110	0 KHz- 1,5 GHz
2	Antenna (circle)	-	-
3	Conic antenna EMCO	3108	30 MHz-300MHz
4	Spectrum analyzer Hewlett Packard -8620 C 86220 A 86235 A 86245 A	HP	1.7 GHz- 4.3 GHz 5.7 GHz- 10 GHz
5	Receiver antenna	P6 –23 A	1GHz-18 GHz
6	Shielded room	-	-
7	Measuring receiver equipment Carnel Labs	NM 67A	1GHz-18 GHz

For the measuring of permeability, permittivity, and conductivity of magnetic composites at microwave frequencies we using this complete experimental setup:

The main component of the setup is a coaxial transmission line (RAFENA-WERKE, Type DML -112A, 0.5 - 3.5 GHz bandwidth, characteristic impedance Z_0 = 50 Ω) equipped with a RF detector. The output dc voltage provide by RF detection probe is applied to a digital voltmeter.

The coaxial transmission line is excited by a microwave signal generator (TESLA, Type TR-0611). In order to avoid the signal generator overload the coaxial transmission line and signal generator are separated by a calibrated attenuators chain (ROHDE&SCHWARZ, Types DPF BN 18064 and RBD BN 33661, 0-4 GHz bandwidth). The test holder is composed of two concentric conductors separated by an empty space. The inner diameter of the outer conductor and the outer diameter of the inner conductor are D=24 mm and d=14 mm, respectively. The calculated characteristic impedance of the test holder is found to be Z_M = 32 Ω. Within the test holder is placed the sample under test. The sample outer and inner diameters are 23.5 and 14 mm, respectively. The test holder dimensions has been chosen to match to the sample dimensions.One of the test holder extremities is connected to the coaxial transmission line while the other can be connected to a Z_z = 50 Ω calibrated load or can be terminated with a transverse sheet of metal Z_z = 0 (short circuit). The expressions of the Z_f and Z_X as function of Z_i are obtained. If Z_X is known, then the following relations may be written:

$$th(\gamma w)=\frac{e^{\gamma w}-e^{-\gamma w}}{e^{\gamma w}+e^{-\gamma w}}=\frac{e^{2\gamma w}-1}{e^{2\gamma w}+1}=\frac{Z_{f0}}{Z_X} \text{ or } e^{2\gamma w}=\frac{Z_X+Z_{f0}}{Z_X-Z_{f0}} \quad (1)$$

$$\alpha=\frac{1}{2w}\ln\left|\frac{Z_X+Z_{f0}}{Z_X-Z_{f0}}\right| \quad (2)$$

4. Results and discussion

Relations (1) and (2) allow to calculate the parameter of MW attenuation α. On the other hand if the parameters of MW attenuation are known, the permeability, permittivity and conductivity of the sample can be calculated [4]. The attenuation of the RF field is described by the real part α of the propagation constant γ (attenuation constant).

Table 3 shows the attenuation of shields prepared from ferrite 50% + pyrites ashes 50%.

Fig. 2 shows the comparison of the attenuation for magnetic shields obtained from ferrite 50% + pyrites ashes 50% and pyrites ashes 100%, mixed with epoxy-acrylic resin and rubber.

Table 3.

Sample1 -■-/ Composite: ferrite + pyrites ashes		Sample2 -●- / Composite: ferrite + pyrites ashes	
Frequency (MHz)	Attenuation (dB)	Frequency (MHz)	Attenuation (dB)
800	48	800	48
900	56	900	58
1 000	48	1 000	48
1 300	53	1 300	64
1 700	35	1 700	37
2 300	43	2 300	43
2 500	40	2 500	37
3 300	42	3 300	45
3 500	47	3 500	44
5 900	53	5 900	48
6 500	41	6 500	40
7 000	58	7 000	47
7 500	40	7 500	37
8 000	40	8 000	39
8 500	35	8 500	32
9 500	51	9 500	48
10 000	20	10 000	24

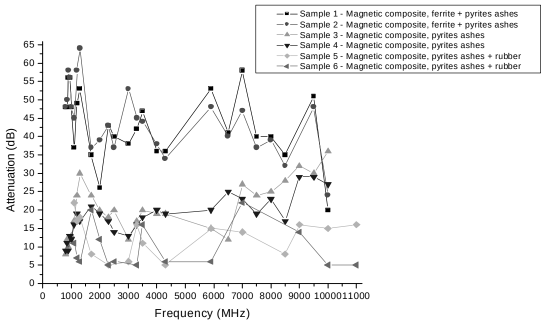

Fig. 2. The attenuation vs. frequencies, for magnetic shields obtained from 50 % ferrite + 50 % pyrites ashes, 100 % pyrites ashes, and pyrites ashes +rubber.

5. Conclusion

We conclude that the magnetic composite obtained from 50% ferrite + 50% pyrites ashes mixed with epoxy-acrylic resin is a good candidate for use as wide bandwidth electromagnetic microwave absorber and shield.

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