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Barium-containing cement and concrete for protection against electromagnetic radiation

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The results on the production and testing of materials based on barium-containing cement with a barium hexaferrite filler and concrete based on them are presented. High rates of shielding of electromagnetic radiation in the frequency range 80–100 kHz make it possible to recommend these building materials for the protection of biological and technical objects from the effects of electromagnetic radiation.
Keywords: electromagnetic radiation protection materials, barium-containing cement, barium hexaferrite, special concretes, ferromagnetic properties.

Барійвмісний цемент та бетон для захисту від електромагнітного випромінювання. *Г.М.Шабанова, А.М.Корогодська, М.В.Кустов, О.В.Христич, С.М.Логвінков, М.Ю.Іващенко, Д.В.Тарадуда*

Представлено результати отримання і випробувань матеріалу на основі барійвмісного цементу і заповнювача — гексафериту барію, а також бетону на його основі. Високі показники екранування електромагнітного випромінювання в діапазоні частот 80–100 кГц дозволяють рекомендувати дані будівельні матеріали для захисту біологічних і технічних об'єктів від впливу електромагнітного випромінювання.

Представлены результаты получения и испытаний материала на основе барийсодержащего цемента и заполнителя — гексаферрита бария, а также бетона на его основе. Высокие показатели экранирования электромагнитного излучения в диапазоне частот 80–100 кГц позволяют рекомендовать данные строительные материалы для защиты биологических и технических объектов от воздействия электромагнитного излучения.

1. Introduction

One of the affecting factors of a nuclear explosion is a powerful pulse of electromagnetic radiation [1]. Electromagnetic radiation destroys all electromagnetic devices in the area affected by the radiation. The problem of protection of such systems is of great importance.

According to the National Security System, vitally important life-support units and systems should be located in special protective facilities [2, 3]. However, the available

Table 1. Physical and technical properties of barium-containing cement stone.

Item No	Indices	Barium-containing cement stone	Ferromagnetic ceramics
1	Residual induction, Tl	0.21	0.28
2	Coercive force, kA/m	340	276
3	Specific electrical resistance, Ohm·m	$1.5 \cdot 10^5$	$1.6 \cdot 10^6$
4	Curie temperature, °C	465	320

technologies and materials used for these purposes require placing them deep underground or using thick-walled metal structures. Therefore, the development of new materials resistant to the penetration of electromagnetic radiation will significantly simplify the design of protective facilities and provide an increased level of the protection for electrical equipment.

Ferrites with a low value of magnetic permeability (one of the defining indices for the radiation protection) at low frequencies are the most promising choice for creating the materials that protect against electromagnetic radiation. Available compositions of the materials possess good protective properties. However, these are rather expensive and difficult to manufacture. Therefore, a promising approach to the solution of this problem is to create the materials with an appropriate combination of physical, mechanical and protective properties, which can be obtained without the use of complex technologies. As for building materials, the problem can be solved using special cement. The development and use of special barium cements and barium cement-based concretes for the construction of protective facilities will significantly increase the resistance of such structures to the effects of electromagnetic factors.

2. Experimental

The purpose of this research was to synthesize the experimental composition of cement clinker, to use it for the manufacture of concrete specimens and to study their physical, mechanical and protective properties.

The set of investigations carried out for the $Ba–Al_2O_3–Fe_2O_3$ [4] system allowed us to select a rational composition for the barium-containing cement based on barium monoaluminate ($BaAl_2O_4$) and barium hexaferrite ($BaFe_{12}O_{19}$) that can efficiently be used as a binder for the production of special concretes and composite materials that are resistant to the simultaneous action of elevated temperatures and radiation.

Industrial barium carbonate, alumina and iron oxide were used as raw components in proportion required for the formation of barium monoaluminate and barium hexaferrite in the clinker. The synthesis was conducted at the temperature of 1300°C, the isothermal curing time was three hours. The obtained clinker was ground to a specific surface area of 400 m^2/kg.

The principal characteristic of the ferromagnetic properties of the material is its magnetization curve, i.e. the dependence of the residual magnetization of the specimen on the magnetic field intensity.

All the specimens prepared on the basis of the selected barium-containing cements with a high content of hexaferrite have ferromagnetic properties. Table 1 gives physical and technical properties of the synthesized ferromagnetic barium-containing cements stone and known ferromagnetic ceramics [4].

The use of the developed barium-containing binders based on barium aluminates and barium ferrites has an advantage over ceramics; this makes it possible to manufacture non-fired products with ferromagnetic properties of complex configuration and large dimensions.

To obtain protective concretes based on barium-containing cement with ferromagnetic properties, barium hexaferrite (80 wt.%) and cement in proportion of $BaFe_{12}O_{19}:BaAl_2O_4 = 4:1$ and in the amount of 20 wt.% were selected as aggregates.

Barium hexaferrite has a hexagonal crystalline lattice with the single-axes anisotropy and it is used as a ferromagnetic material [7]. The magnetic properties of barium hexaferrite are due to uncompensated antiferromagnetism that is characterized by a low value of residual induction and a high value of maximum magnetic energy. Barium magnets obtained on the basis of barium hexaferrite have a high cohesive force (240 kA/m), high resistance to magnetic fields, vibrations and shocks, withstand structural aging and do not contain critical elements [8].

Table 2. Dependence of the concrete strength and porosity on the composition

Amount of cement, mass %	Amount of aggregate, mass%	Compression strength margin, MPa at the age of days and nights		Open porosity, %
		7	28	
10	90	43.2	42.8	23.2
20	80	54.2	54.0	19.7
30	70	59.7	59.2	18.5
40	60	62.3	61.5	18.0
50	50	64.6	64.0	17.2

3. Results and discussion

Concrete specimens with dimensions of 20×20×20 mm were fabricated using the vibromolding method (water/solid = 0.8). To define an optimal ratio for the size of grains of adjacent aggregate fractions we used the formula given in [9]. The quantitative ratio of the adjacent aggregate fractions was optimized using the method of simulating a simplex-lattice experiment [10]. To obtain the concrete of high strength, density and homogeneity, a three-fraction aggregate mixture with a given rational quantitative ratio of grain size (wt. %) is required: the fraction of 1.0 to 0.6 mm is from 20 to 30 wt. %; the fraction of 0.6 to 0.315 mm is from 30 to 50 wt. %; and the fraction less than 0.315 mm is from 40 to 60 wt. %. The properties of concrete were studied taking into consideration the optimal particle size distribution of the aggregate.

The method of vibromolding was used for the fabrication of the specimens with dimensions of 40×40×40 mm, based on barium-containing cement with ferromagnetic properties and barium hexaferrite used as an aggregate of a specified functional composition with the water-to-solid (W/S) ratio equal to 0.085. The physical and mechanical properties of concrete were studied depending on the aggregate-to-cement ratio in it; the obtained data are given in Table 2.

The analysis of the research data (Table 2) show that an increase in the content of cement in the concrete mixture results in an increased strength of the hardened concrete and in a decreased porosity. This indicates that the added cement is actively involved not only in the formation of concrete strength, but also in the reduction of porosity. The concrete compositions are characterized by high strength indicators (from 48 to 50 MPa) and ferromagnetic characteristics due to changes in the phase relationship. A two-position installation of a quasi-optical type was used to study the protective properties of the specimens of barium-containing cement and the concrete based on it under the action of electromagnetic radiation [11]. During the tests, the radiation power transmission coefficient and the reflection coefficient were measured at the frequencies of 80, 84, 88, 92, 96 and 100 kHz. The electromagnetic wave absorption coefficient was derived from the formula:

$$A = 1 - (R + T),$$

where A is the absorption coefficient; R is the reflection coefficient, T is the transmission coefficient.

The electromagnetic wave shielding coefficient was calculated using the following formula:

$$E = A + R.$$

Table 3 gives the research data of the protective properties of the compositions of barium-containing cement and the concrete based on it.

According to the research results, the screening factor is increased with an increase in the thickness of the layer of the developed material. The data given in Fig. show that the specimens made of the developed material have higher indices of the shielding factors in comparison to those of known protective materials.

The use of the developed barium-containing materials will significantly simplify the design of protective structures and increase the level of protection of electrical equipment, maintenance personnel and various control, communication, monitoring and life support systems from the negative effects of electromagnetic radiation. The developed cement can also be used as a plaster component; the applied layer should be 3 to 6 mm thick that will allow us to reduce the intensity of electromagnetic radiation on average

Table 3. The shielding factor of obtained materials, dB

Item No	Specimens	Specimen thickness, mm	Radiation frequency, kHz					
			80	84	88	92	96	100
1	Barium-containing cement stone	10	21.23	23.42	23.82	24.25	24.87	25.28
2	Concrete	10	23.93	25.36	25.62	26.38	27.05	27.42
3	Special ceramic	10	18.50	21.50	21.80	24.10	24.50	25.00

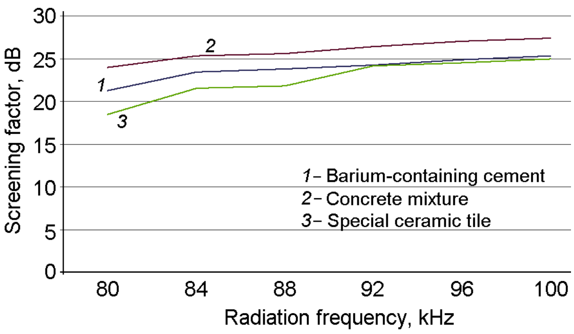

Fig. Comparative characteristics of shielding factors of materials (thickness of 10 mm) as a function of radiation frequency.

by an order of magnitude in the frequency range of 80 to 100 kHz.

Original design solutions can definitely lead to a significant decrease in the level of the electromagnetic field generated not only inside the protective structure, but also in individual rooms.

4. Conclusions

According to the research results, the obtained materials based on barium-containing cement and barium hexaferrite aggregate have high rates of shielding of electromagnetic radiation in the frequency range of 80 to 100 kHz and high strength characteristics (48 to 50 MPa). Therefore, these construction materials can be recommended for the protection of biological and technical facilities exposed to the action of pulsed electromagnetic radiation. In addition, these construction materials increase the resistance of such facilities to the action of radiation factors. In addition, concrete technologies can be used to manufacture products of complex configuration and different sizes for EMR protection in various industries.

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