COMPOSITE RADIATION-SHIELDING CONCRETE FOR SPECIAL PURPOSES

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Systems of engineering-technical solutions, aimed at creation of the suitable sanitary-hygiene conditions for the operation of nuclear energy units provide the installation of the protection barriers in the form of the radiation-absorbing coating and special screens. The aim of the radiation protection is the prevention of the somatic and reduction to minimum somatic-stochastic genetic effects, caused by the impact of the external and internal radiation of both separate person and population on the whole in the process of operation, storage and transport of the radioactive substances, operation of nuclear reactors, X-Ray units and other sources of radiation.

World experience shows that in the process of construction of the nuclear engineering facilities , nuclear waste repositories, construction of civil defense objects various concretes are widely used. For the construction of the nuclear facilities, repositories,containers for nuclear waste in domestic and foreign practice ordinary concretes are used. Such material consists of the elements with small and mean atomic weights (second group), which are used for shielding the direct and indirect- ionizing radiations. In separate cases installation of the biological protection by means of cement concretes on the condition of the increase of the thickness of the protection shield is more efficient than metal and lead water shielding [1 - 6].

The possibility to use heavy concretes as the construction composite materials of biological protection is provided due to the accessible technology of the raw mixture composition regulation, which enables to use the conventional binding systems by the main components. Regulation of the radiation-protective properties is realized as a result of usage of the special fillers, able to enter physical-chemical interactions with the binding component as a part of the forming specialized construction mixtures [7 - 10]. Usage of the chemical elements with various ordinal numbers in the concrete enables to optimize and interconnect mechanical, physical and special protective properties against ionizing radiation [11 -12].

Application of the fine metal powder (waste of the machining production) as heavy concrete filler is the result of obtaining new kind of concretes on the base of mineral binders – electric conducting metal-saturated concrete. From the point of view of the researchers investigating the microstructural processes of the dispersea-filled mineral matrix structures formation the obtained composite material is a complex interpenetrating heterogeneous system, the properties of each element of this structure differ. Hardened newgrowths of the binding system is a dielectric matrix and reaction-able metal powder is electric conducting component of the material. As a result of the uniform distribution of the metal particles in the matrix array, the structure of the cement brick is formed, the given structure is the analog of the cement concretes with mineral disperse additives. The improved adhesion between the particles of the heavy electric conducting filler and binding components of the mixture, coincidence of the linear deformations of the cement brick and metal, wide range of electric resistance are the result of the obtaining of the composite material with wide range of the constructive and physical mechanical properties, improved heat transfer.

Artificial synthesis of the dense structures of the disperse-filled conglomerate with large area of the internal surface of the phase distribution will also influence the weakening of the penetrating fluxes of the shielding material. As the volume electric conducting matrix is formed in the structure of the metal-saturated fine disperse concrete and photonic electromagnetic radiation, according to the laws of the quantum physics has wave and corpuscular properties, then the absorption of the radiation in the structure of the material will occur by the excited in the volume of the electric conducting matrix counteracting field and at the expense of the repeated reflections and scattering of the radiation flux on the surface of the disperse metal filler. Saturation of the cement binder with the metal powder and formation of the iron-containing hydraulic silicates with the elevated content of the constitutional water will approach the obtained concrete by special properties to the multilayer metal water shields [13-15].

As a result of the impact of the ionizing radiation on the materials of the radiation protection shields structural and chemical changes take place in these materials, accompanied by the decrease of physical and mechanical properties [16-17]. The volume of these changes depends on the type of the material and component and energy structure of the radiation, that is why, at high intensity of the radiation and its long duration the designers face the problem of the development of the radiation-protection concretes.

Addition of the steel fillers to the concrete leads to the improvement of its radiation-protective and physical mechanical properties but depending on the kind of geometric forms, content of the fillers and its chemical composition. Mechanical properties of the concretes on the scrap steel are worsened as compared with the ordinary concretes, although without particular complications the material with the volume weight of 5.4 t/m^3 can be obtained. In [18] it is shown that the usage of the waste of milling of the coarse aggregate and cast-iron shot as small filler enables to obtain density of 6.8 t/m^3.

In research [19 -21] the authors suggested the usage of the machining waste (metal slurry) for the obtaining of the new kind of the concretes with the polyfunctional properties. Fine disperse ShKH-15 steel slurry is obtained as a result of complex technological process of balls fabrication at ball bearing plants. The components of the process are cold forging, high speed mechanical peeling, carbide grain grinding, quenching, tempering , solid grinding, finishing and polishing. In the process of manufacturing moist junk removal of the waste by the turbulent flow of the lubricating-cooling fluid is used. Characteristics of the sludges powder depends on the manufacturing process, technological characteristics of the operations of which influence the mechanical properties of the powders and their dimensions (Table 1).

Depending on the method of the waste storage they may differ by the content of the oxide inclusions. Metal powders, used directly from special settling tanks where they are removed by the flux of cooling fluid during manufacturing operations, are characterized by small degree of oxidation. When metal waste from the disposal area is used (storage in the open air), such fillers are characterized by considerable metal oxides inclusion, formed in the process of long storage. Traces of lubricating-cooling fluids on the surface of the particles of metal powders is common for these two kinds.

Table 1

Characteristics of the sludge waste of ShKH-15 steel [22 -25]

Components of the lubricating-cooling fluid for the technological operations of the metal working	C_{Fe}, %		$d\times10^3$, kg/m^3	5×10^3, m^2/kg	$r_{max}\times10^{-6}$, m
	Output metal	Powder			
1. Balls rolling					
Emulsion on tall oil, sodium carbonate, sodium nitrate.	60.1	90.5	5.9	0.7	45.0
2. Balls grinding					
Diesel fuel, stearine.	75.0	83.7	4.5	1.0	7.5
Water, triethanolamine, sodium nitrate.	29.4	85.4	5.0	1.5	10.0
Water, sodium carbonate, sodium nitrate.	54.0	89.5	6.7	2.0	15.0
Water, sodium carbonate, sodium nitrate, sodium phosphate.	80.5	95.4	7.2	0.5	27.0
3. Path grinding					
Emulsion, triethanolamine, oleic acid.	23.0	66.0	4.2	0.6	35.0

For the usage of the metal waste as the concrete fillers it is necessary to apply additionally the technology of tertiary treatment, which can be realized by means of two operation processes: annealing without the access of oxygen at + 500 ÷ 700^{0}C or washing of the traces of the cooling substances in alkali water. It is expedient to use metal powders (waste of ShKH-15 steel) as concrete filler on the base of mineral binders for the production of radiation-protective shields from the open disposal areas, i. e., with the oxidized metal surfaces. High content of oxygen on the surface of the oxidized layer of metal powders at the contact with the binding element may cause the formation of elevated content of the chemically bound water [26-28].

Basic technologic parameters which further will influence physical, mechanic and operational properties of new type of cement concretes with metallic fine disperse fillers will be indices of the quantitative ratio of the raw mixture components. Among these parameters water flow, consumption of binding, additives and metal powder content are main parameters. These formulation- technological parameters will influence physical, mechanical and rheological parameters of the formed solutions – mobility of the conglomerate mixture, volume weight and strength of the studied samples, technological modes of the products hardening.

From the point of view of the radiation protection properties of the metal-saturated concrete, main functional component is fine disperse filler which is metal powder in laminar or husk-like form with average size of 0.02 mm. As a result of such form of the dump waste of metal working productions the cavitation of the metal slurry reaches 75%. In the research metal, cleared from the traces of the lubricating-cooling fluids by means of washing in the alkali solution at the temperature of $+50^0$C was used. Real density of the dried powder equals 6.76 g/cm^3, and bulk density – 1.31 g/cm^3. In [29] authors determined that after the vibration during 3 – 4 minutes the bulk density of the cleaned powder increases to 2.76 g/cm^3.

The criterion of the concrete density is interpenetration of the binding element and disperse filler, which depends on the number and the character of the pores of the formed structures. Main kinds of pores in fine disperse metal-saturated concrete will be cavities and pores in matrix body of the cement stone and material in general, which were formed as a result of mixing and arrangement of the mixture. Small pores and capillary (1÷50 μc) will be formed between the grains of the cement brick and filler, formed as a result of the evaporation of the structural and porous unstable-bound water of the newgrowths. Micropores (5–20 μc) of the hydrated helium shells, which appeared as a result of the contractional phenomena in the process of the hydration of the mineral binding may be referred to the type of micropore looseness. In the fine-grain metal -saturated concrete the porosity is caused by the form of the particles of metal fine-disperse filler, their aggregation into the floccules in the presence of water [30- 35].

Studies of the impact of the formulation -technologic parameters on the properties of the forming solutions were carried out for the metal-cement mixtures and for the solutions with the addition of fine fillers. Fine-disperse metal-saturated composite material should be considered as the concrete with microfiller. In the given case metal powder and mineral binding may be considered as an integral unit – metal-cement paste. The cement activity and its impact on the water content in the mixture will depend on the content and properties of the disperse heavy filler. Powders of ShKH-15 steel due to large specific surface (S_{spes} = (0,5-2)×10^3 m^2/kg) and high hydrophilic property increase the water need of the mixture (Fig. 1). As a result the porosity of the material increases due to the excess water, that does not participate in the hydration of the mineral binder.

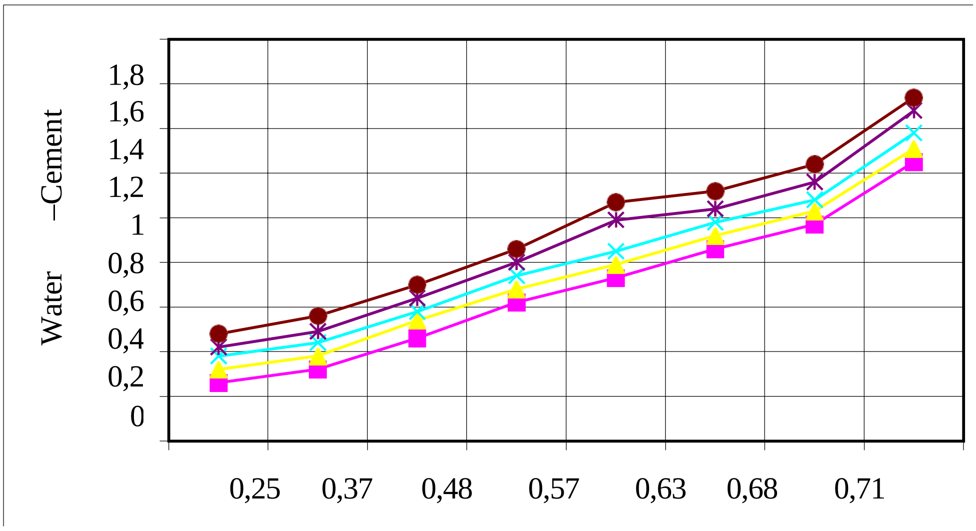

Fig. 1. Impact of the metal filler content on the water needs of the mixture samples: 1 – small come spread on the shaker apparatus 101 – 108 mm; 2 – the same 112 – 122 mm; 3 – the same 126 – 133 mm; 4 – the same 144 – 149 mm; 5 – the same 158

From the materials of the graphic interpretation of the results of the experimental studies, shown in Fig. 1, it is observed that with the increase of the metal microfiller concentration in the mixture water needs of the formation solutions increase at the determined limits of rheological parameters of the fine grain concrete samples. The impact on the mobility of the studied samples of the metal- saturated mixtures of the quantitative ratio of the components at the preset indices of water-solid ratio is observed. Technology of the shielding coating manufacture from pourable metal-saturated mixtures will lead to the obtaining of the units with high indices of the structure porosity that further will negatively influence radiation-protective properties of the material.

The results of the experimental studies of physical-mechanical characteristics of the metal- saturated samples, manufactured applying the technology of plaster coverings show that the amount of the metal powder in the composite material influences differently on the average density index of the sample. With the saturation of the cement brick with the dispersed metal, the density of the samples increases from 1.73 to 2.04 g/cm^3. Specific content of the metal filler is within the limits from 0 to 36% of the mass. Further as the content of the microfiller in the structure of the cement brick increases , the index of the average density of the samples gradually decreases and equals 1.62 g/cm^3 at the concentration of the heavy filler 80% of the pts [36 - 38]. It is explained by the high porousness of the steel ShKH-15 powder and correspondingly, considerable water needs of the solution for the set mobility.

Addition of the dielectric filler to the composition of the formation solutions, manufacturing according to the technology of the plaster covering of the mineral filler – glass sand leads to the growth of the average density indices of the samples structure as the amount of the metal powder increases to 30% . As the porousness of the sand on average is 36%, it is obvious that the increase of the amount of the metal cement paste results in the separation of the particles of the dielectric filler and increase of the material porosity. Further increase of metal concentration to 50% results in the decreases of the samples density up to 1.8 g/cm^3 [39 - 41].

Usage of the mechanical impact on the formation of the samples-models structure of the radiation-protection shield with fine grain metal -saturated concrete (rigid mixtures) by the means of static pressure of 20 kg/cm^2, results in the increase of the average density of the samples of pressed tiles as compared with the products, fabricated, applying the technology of plaster coverings. Under the impact of the compaction the removal of the free water occurs and the rigid fixation of the metal particles in the hydrated matrix of the mineral binding material is carried out. When the cement binding is saturated with the microfiller to 56% the average density of the samples is 2.6 g/cm^3, for the models of the plaster coverings at the same concentration of the heavy filler the value of ρ_m is 1.76 g/cm^3. [42 - 44]. As the amount of the metal powder increases to 86% the density of the sample decreases to

2.28 g/cm^3. The addition to the mixture of the coarse dielectric filler also by analogy with the plaster mixtures changes the value ρ_m of the samples. Coarse particles of the sand in the process of mixture preparation destroy the aggregates of the metal particles. As the concentration reaches 80% the average density of the samples equals the maximum value – 2.87 g/cm^3 [45 - 47].

The conducted studies confirm the possibility of installing a radiation protective coating both by the technology of performing plastering works and by making a screen from prefabricated elements - pressed tiles. Analyzing the processes of attenuation of ionizing radiation by protective screens, it is quite obvious that it is possible to increase the efficiency of attenuation of ionizing radiation for pressed samples [48 - 50].

One of the technological methods of increasing the density of the structure of the samples of the radiation-protection coating made of the fine grain metal-saturated concrete may be the application of the surface-active additives in the content of the mixture. To decrease the amount of the excessive water, caused by high hydroscopic property of the metal filler in the process of mixture preparation it is expedient to use plasticizing agents.

The precondition for the availability of special radiation-protection properties of the obtained concrete samples can be explained after the analysis of the ionizing radiation weakening in the process of the interaction with the absorbing substance as it gradually penetrates across the thickness of the material. That is, at the expense of filling of fine grain cement concrete with the dispersed very heavy filler, the density of the composite increases. Saturation of the cement binding with metal powder and formation of iron-containing hydrosilicates with the elevated content of chemically bound water approaches the developed composite material by special properties to multi-layered metal-water shields (attenuation of the mixed n and γ – radiation) [51].

Technological parameters of the fabrication of fine -grain radiation-protection concretes are provided by the usage of the metal powders as the filler. The ability of the metal -saturated concrete to shield ionizing radiation can be explained by the creation in the structure of the composite volumetric electric conducting matrix as a result of filling the binder with fine-disperse conducting component. Such material has large phase boundary surfaces, on the microscopic level this can be considered as the analogy of the multilayered constructions of the barrier protection in the form of variotropic screens.

Cement concretes are referred to the second group of the radioprotection materials. Their physical chemical composition contains elements with small and mean ordinal number. Average density of the obtained samples is 2,0÷2,9 g/cm^3. Construction materials, manufactured from the metal-saturated concrete by their radiation-protective characteristics occupy the intermediate position between the aluminium screens and protective barriers, made of lead (Table 2).

Table 2

Linear coefficients of attenuating γ-radiation of the available protective materials [52-54].

Material	ρ, g/cm^3	Energy of γ- quanta						
		0.2 MeV	0.4 MeV	0.6 MeV	0.8 MeV	1.0 MeV	1.5 MeV	2.0 MeV
Aluminium	2.56	0.32	0.25	0.20	0.18	0.16	0.19	0.12
Concrete	2.35	0.291	0.224	0.189	0.166	0.149	0.122	0.104
Lead	11.3	10.7	2.44	1.33	0.95	0.77	0.66	0.56

Designing biological protection against ionizing radiation it should be taken into account, that along with special properties the materials of the shielding constructions must meet a number of the requirements for the conventional construction materials. In the production process the technological procedures of barrier protection manufacturing must be strictly observed.

From the results obtained and presented in the study the conclusions can be made that depending on admissible thickness of the protection screen radiation-protective concretes can be used as the monolithic plastering or as the preassembled covering, made of the pressed tiles. It is quite obvious that the efficiency of the ionizing radiation attenuation will prevail in the pressed samples but the problem of the tiles butting must be solved to eliminate the possible “shooting” of the radiation fluxes between the tiles.

The regulation of the formulation-technological parameters of radiation-protective concretes, using fine-disperse metal filler in the structure of the material and creation as a result of physical chemical interaction mineral binding and reaction-able metal filler of the volume heterogeneous matrix in the form of variotropic structures in the body of the manufactured screen provides obtaining by the composite material elevated screening properties.

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