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Fine-Dispersed Mineral Admixture-Modified Polystyrene Concrete

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Abstract
In the modern construction much attention is paid to the issues of energy-saving and heat-insulation. The use of industrial wastes as mineral additives for manufacturing of heat-insulating materials is an efficient method of enhancing the buildings heat insulation. The objective of the studies described in this paper was design of compositions of polystyrene concrete with addition of finely dispersed slurry – wastes of chemical industry. The paper presents the method of improvement of the physico-mechanical properties of the heat-insulating polystyrene concrete. The results of investigation of the effect of mineral additives containing oxides of transition metals (iron, manganese, nickel) on the strength of the cement paste and mortar are provided. The results of the Mossbauer spectroscopy of the cement paste with addition of the ferrous oxide are presented. It was found out that in the cement binding agents in the presence of dispersed slurry containing oxides of transition metals the processes accompanied by the charge transfer take place. Ions of transition metals contained in the slurry added are good acceptors of electrons in the alkaline environment and facilitate the redox-processes by the cement hydration. The optimum quantity of the slurry additive for production of polystyrene concrete was determined. The polystyrene concrete compositions with the density 300-350 kg/m^3 and the compression strength 2,5-2,7 MPa were obtained with the use of the nickel-containing slurry.

Keywords:lightweight concrete, mineral admixtures, density, physical and mechanicalproperties.

1. INTRODUCTION

In today's construction industry the power conservationproblemis solvedin different ways.The enhancement ofheat-protection properties ofenclosing structuresremains the mosteffective wayfor power conservation improvement for both newand existingbuildings and structures.A wide range ofinsulating materials ofdifferingproperties, composition andscope are currently used to winterize the enclosing structures.Most of thesematerialshave a numberof disadvantages:low strength, low durability,flammability, susceptibility to aging and lack ofenvironmentalsafety. The modernheat-insulation materialsshould be easyto produce,made fromreadily available materials, have highmechanical propertiesandbe competitiveacross a widerange ofinsulating materials.The example ofsuch a material ispolystyrene.

The properties of anycomposite materialdepend on the propertiesof the matrix, the type of matrixinteractionwith the fillerand other factors[1]. Thispaper deals with the issues of the modification of the cementmatrix ofpolystyrene concrete in order to improvethe strength, thermophysicalandhydrophysicalpropertiesto expandthe field of its application.

The functionalproperties of polystyrene are close to those ofcellular concrete. Cement is polystyrenematrixandexpanded polystyrene–its ultra-lightweight filler.The propertiesof polystyreneconcreteasthe composite materiallargelydependonthe structure andproperties of the matrix; the mean densityandexpanded polystyrene grading; on the chemicalagentsadmixed tothe cementmatrix;the technologyfor polystyrene concrete production and otherfactors[2-5].

2. FFEDBACK CHARACTERIZATION

We used M400 Portland cement as the cementfor polystyrene concrete mixing.

As the filler we used the 0-10mm gradeexpanded polystyrene with a bulk densityof 10-15 $kg/m^3$of the followinggrading: 0-5 mm grades – 30-40% by volume, 5-10 mmgrades – 70-60%.

The ironslurryis ablackfine powderwitha specific surface areaof 150 m^2/kg, comprisingiron oxide(III) 73,0 - 75,0%,iron oxide(II) 17,0 - 17,2%andaluminaoxide9.8-10.0%

Nickel-containingsludgeiscaprolactam production waste, which is a fine powderof black colorwith a surface areaof 300-350 m^2/kg with the true density of3500-3700 kg/m^3, the average density of3500-3700 kg/m^3.The sludgecontainsnickel(II) oxide- 92-93%,aluminum oxide-5-6%insolubles- 2-3% ignited residue - 85%, pH of aqueous extract - 8-9.

BenotehPMP-1 admixture meetingspecifications 5870-001-56025130-01 is designedfor the production ofconcrete and cement-based mortar. It is ahardeningacceleratorwith anti-freeze effect; ithasplasticizing propertiesand provides the cement hardeningat negativetemperatures up to-25°C.BenotehMSP-1 is a light-yellow color liquid of 1,3 ± 0,03 g/cm^3 density.PH value(pH) is9± 1.

3. EXPERIMENTANDDISCUSSION

At the initial stage weinvestigated the effectsof iron, manganese and nickel oxide admixtures on the strengthof the cement and the cement-sand mortar on the 4×4×16 cm samples. Theadmixtureswereadmixedin an amount offrom 1 to12% by cement weight.The analysis of the resultsof the experimentsshowed thatoxide admixturesincrease thestrengthof the cement by12-24%, and thecement-sand mortar- by9-18%.

To clarifythe causesof this phenomenonthe experiment was conductedusing theMossbauer spectroscopy, which allows tracking the changes inthe oxidation state ofthe elementdirectly in thehardeningcement. The spectrawere recorded atroom temperaturefromthe mixing point up to28 daysin the presence ofadmixed iron(III).The spectra recordedare shown in Figure1.

The spectrumof feed iron has a doublet with the isomericshiftof 0.40mm/s andquadrupolesplitting of 0,680 mm/s atpeak width of 0,24 mm/s (curve1).The spectrum recordedat the mixing moment ofthe cement with admixtureis identical tothe feed admixturespectrum.

Three hours aftermixing the small peaks withisomericshift of 1,90 mm/s and isomericshiftof 3,95 mm/s appeared in the spectrum ofaluminosilicatecementwith the admixture. Over time,the intensity ofthesepeakswas increased byreducing the intensity ofthe doublettypical for the feed iron admixture(III).

The decreasein the spectrum ofthe feed doublet linesshowsthatthe partialreduction of iron(III) occurs.The spectrum of magnetic cropextracted from the hardening system showed the presenceof reducedα-iron with theisomer shiftsat ratesof 0.81; 3.06; 5.243mm/s(curve3)in the products ofhydration. Thatis, during thehydrationan intensiveinteraction between the admixture and the cementand the partialreduction of iron(III) toα-iron occurs.

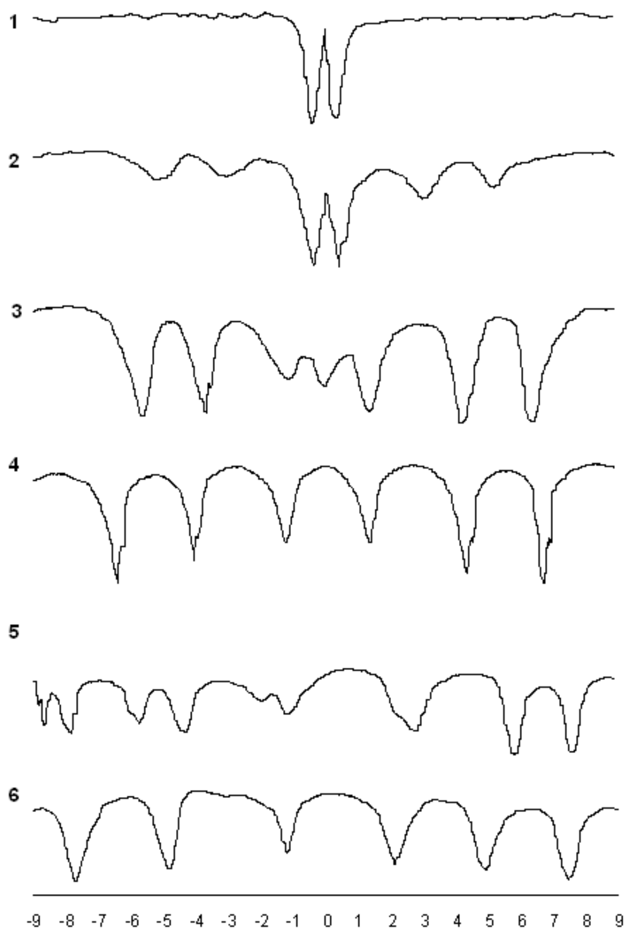

Fig. 1.Mossbauer spectra ofportland cement with iron (III)admixture: 1 – feed cation Fe^{+3}; 2 – cement with admixture three hours after setting; 3 – magnetic crop, extracted from cement; 4 – α–Fe; 5 – Fe_3O_4; 6 – $[FeO_6]$.

The hydroxidecalcium contained in thehardeningsystemleads tothe splittingof silicon-oxygen ties andthe charge transfer processes occur in the heterogeneous system. This is facilitated bythe conditions of existence of structuredwaterwith lowdielectric constantand the high defect rateofthe clinker mineral surface.The admixturediron (III)ionis a goodacceptor of alkalinemedium electrons.Takingelectrons to4d-sublevel, it promotes theoxidation-reductionprocess.The portionof iron(III)is reduced toα-Fe,and the partbecomeshexad coordinationwith quadrupolesplitting of0.65mm/s(curve4).

These data confirm the position [6] that the insoluble compounds of ionic nature, such as solid acids, can accelerate the reaction, and they will be donating a proton, accepting an electron pair; and solid bases may be an electron pair donor, accepting the proton.

The results showed that the introduction of transition metal oxides largely influences on Portland cement matrix to improve the properties of the cement paste and cement-sand mortar and, consequently, on materials such as concrete.

The selection of the optimal amount of admixture was performed using the methods of mathematical planning of experiments: the number of admixtures and water-cement ratio are taken as variable factors, and strength under uniaxial compression - as an optimization parameter. The central rotatable composite design for the yield surface was adopted to construct the quadratic model. Analysis of the resulting mathematical model showed that the optimal amount of iron sludge is 4.5 - 5.0%, nickel sludge - 3.5 - 4.0% by cement weight.

At the final stage of the research we determined the optimal composition of polystyrene concrete with the nickel-containing sludge admixture.

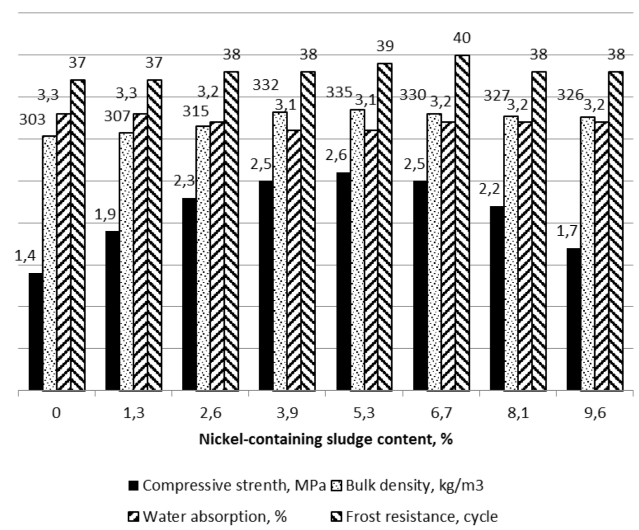

Fig. 2.Influence of nickel-containing sludge admixture on polystyrene concrete properties.

The studies have shownthat the introduction ofnickel-containingsludgeinthe raw material mixturein a rationalamountallows obtainingpolystyrene concrete with acompressive strength ofup to2.1 MPa, water absorption3-4%, frost resistance - 37-40. Mixture ofpolystyrene had hefollowing com-

position, mass %:cement-61,5-62,3polystyrene-5.8, neutralizedair-entrainingresinSDO - 0,15,nickelslurry3.0-5.0, the water - the rest.
In addition, we determined the optimal amount of nickel-containing sludge - 3-5% of the weight that allows determining a set of extreme values [7] of the material properties (Fig. 2).
The increase of the strength of polystyrene with nickel-containing slurry admixture can be explained by two factors: the physical and chemical processes occurring in the cement paste due to the presence of the cation nickel Ni^{+2} in it; changes in the structure of cement paste due to the introduction of fine particulate filler which is uniformly distributed in the cement, producing a reinforcing effect.
The physical and chemical action of nickelsludgepromotes the redoxprocessesleadingto a morerapid crystallizationof newhydrates that enhancethe cement strengthand hardening intensity. As a result of the interaction between the cement and the water,the concentration of OH^-ionsin thecement increasesand the pHreaches10-11. This is enough toensure that the waterprovidesthe protonatedeffect onthe Ni-O system.The introduction of the nickel sludge causes thetopochemical reaction, i.e. the surface reaction which forms the complex with the solid cation. This results in more ionic compound capable of reacting with water. The cation hydration goes easier, which leads to the selective incongruent dissolution. The introducedadmixturecations occupy spaces in the structure and can therefore be hydrated without destroying the carcass of hydrosilicates, but the number of crystallized newgrowths increases and the system strength growth process is intensified [8-9].
In addition, when dispersed inorganic sludge is administered to the cement, its interaction with the cement particles occurs via their contact zone. It is obvious that the optimum amount of sludge admixture will be determined by the size ratio of sludgeand cement particles, when theconstraint hydration reaction environment is being created. It is achieved in the case where the admixture particles are contacted with the most cement particles. Thus, the three-dimensional reinforcement of cement occurs, which prevents micro cracks and promotes redistribution of internal stresses between the cement the admixture particles according to their modulus of elasticity [10].

4. CONCLUSION
The studies conducted have shownthat introduction ofoptimumamount of nickelsludgeinpolystyrene concreteincreasesthe compressive strengthby 80-85%, water absorptiondecreasesby 6-8%, and increases frost resistance.Polystyrene concretewith the nickel-containingsludgeadmixture is an effectivebuilding material; it meets the moderneconomic and environmental requirements, and maybe in demandin today's marketof construction materials.

5.FINDINGS
The studies have shown the possibility and feasibility of using sludge containing transition metal oxides as a part of polystyrene concrete with the purpose of intensification of the cement matrix hydration and improvement of the polystyrene concrete properties.
It has been found that the introduction of transition d-elements inhigh oxidation degree into the cement slurries promotes the activation of cement hydration.
A nickel containing slurry admixture, which contributes to the increase ofstrengthand other physical and mechanical properties of polystyrene concrete.

Conflict of interests
The authors have no conflicts to declare.

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