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Composition Optimization Low Water Demand Cements

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***Abstract**: The article presents the results of studies on optimizing the composition of cement of low water demand using sand dunes and slags. The obtained formulas and isoparametric graphs reflecting the strength of these binders are given.*

***Keywords**: cement, sand dune, Electrothermophosphorus slag, Portland cement clinker, strength, grinding.*

I. INTRODUCTION

Analysis of global economic trends in the field of capital construction, in particular in the production of cementitious materials and cement, shows that the use of resource and energy-saving, innovative technologies and addressing environmental issues is a requirement of the present and the future. The volume of consumption of Portland cement (PC) in Uzbekistan in 2016 amounted to 8462.0 thousand tons. For 2012-2016, the volume of cement production in the republic increased from 6803.5 thousand to 8462 thousand tons, or 24%. Cement consumption per capita in the Republic of Uzbekistan in 2016 amounted to 268 kg (for comparison: in Western Europe - 395 kg, in Russia - 462 kg, in Turkey - 931 kg, the world average - 433 kg). According to forecasts, by 2020 cement consumption per capita in the Republic of Uzbekistan will be at least 328 kg of cement per year [1].

Currently, there are 12 cement plants operating in the country, with a total annual production capacity of more than 9 million tons. However, the achieved level of cement production (about 8.5 million tons in 2016) does not satisfy the needs of the market. An increase in cement production capacities is envisaged through the modernization of existing and the construction of new factories and production lines. Cement has significant environmental disadvantages, the production of which is energy-consuming: equivalent fuel consumption for clinker burning up to 215 kg / t (wet method), electricity for various conversions and grinding - 119 kWh / t of "clean" PC500D0 cement; environmentally damaging - huge volumes of quarrying of limestone and clay (1 ton of cement requires from 1.5 to 2.4 tons of non-metallic raw materials); It is accompanied by large emissions of CO_2 and dust (more than 900 kg of CO_2 and 300–900 kg of dust per 1 ton of PC) [2].

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Therefore, the less clinker in cement, and cement in concrete, the higher the applicability of the latter in construction.

The most important priority area of research in this field of science is the development of nano-technologies and innovative methods in the production of cement and cementitious materials. Cement of low water demand (CWD) is an effective binder based on Portland cement clinker, which has the minimum water demand among currently existing mineral binders. The normal density of CWD is 16%, while that of ordinary Portland cement is 24 ... 30% [3].

CWDs have a number of advantages that can provide a reduction in the consumption of the clinker part of cement by 40 ... 50%, bring binder production closer to construction sites and, as a result, reduce the energy consumption of binder production to 70% [4]. The relevance of the research lies in the fact that according to the proposed technology, it is possible to obtain 1.5 ... 2 times more binders by weight from the existing clinker and significantly save energy costs for its production (80 kg of standard fuel versus 210 kg). In particular, the proposed technology contributes to the solution of economic problems, since it involves the use of industrial waste and flying sand dunes in the steppe regions of the republic [5]. CWD is obtained by joint grinding of Portland cement clinker, an active mineral additive and a special modifier, as well as gypsum stone (gypsum) in fine grinding aggregates. Based on the stated scientific premises, the following tasks were set: optimization of the composition of the central nervous system and the study of its physical and mechanical properties.

II. MATERIALS AND RESEARCH METHODS

A.Raw materials

As source materials for research and analytical experiments were used:

- Portland cement clinker of Bekabadcement Joint-Stock Company.

- "Kyzylkum" flying sand dunes from the region of the Navoi region, consisting mainly of fine-grained sand 92 ... 99%. Physical clay impurities in the composition are contained in a small amount up to 3 ... 4%; dusty particles not more than 1%; during the studies, sand dunes were analyzed for solubility by mixing in hydrochloric acid. The amount of insoluble minerals amounted to 96 ... 97%; soluble - 2.1 ... 2.6%. This shows that the taken silica sand is insoluble;

- Electrotemophosphoric (ETF) slag is a waste product from the Novojambul phosphoric plant - the Dzhambul branch of Kazphosphate LLP.ETF slags are close in structure and composition to blast furnaces, and can also be used with high efficiency in the production of cements.

Gypsum stone of the Kagan deposit in the Bukhara region.
The chemical compositions of the materials used are given in table. I.
The additive "Megaplast-JK 02" was used as a superplasticizer, the chemical composition corresponding to sodium polymethylene naphthalene sulfonates. Affordable, versatile dry powder supplement.

Table I. The content of chemical oxides in raw materials

Name of materials	The content of chemical oxides, % mass											
	Fe_2O_3	SO_3	Al_2O_3	K_2O	Na_2O	FeO	TiO_2	MnO	P_2O_5	SiO_2	CaO	MgO
Portland cement clinker	2...4	0,3...1	4...8	0,1...0,4	0,1...0,4	-	0,2...0,5	-	0,1	21...24	63...68	0,5...5,1
Sands dune	2,2,5	-	7...9,6	1...1,72	2...2,16	1...1,08	0,1...0,54	0,08	Следы	57...68	6...7,56	0,1...0,5
ETF Slag	0,45...4,0	0,2...1,4	0,4...3,0	-	-	-	0,07...0,1	2,0...3,0	0,9...3,0	40...43	42...49	3,0...5,0

B. Research methodology

In accordance with the task, a series of experiments was carried out to optimize the composition of the CWD. CWD production was carried out in a dry manner, i.e. all components with a moisture content of not more than 1 mass. %, in the calculated amount, was crushed in a VM-1000 vibratory mill to the required dispersion. Finished fine powder was investigated as a binder, and the physical and mechanical properties were studied according to GOST 30744-2001 [6]. In order to determine the optimal amount of constituent components and the required specific surface area of the binder, the composition of the components is conditionally divided into two groups: in the first group, "Kyzylkum" flying sand dunes were used as siliceous mineral inclusion; in the second group - ETF slag.
From the obtained TsNV standard samples of the prism 4x4x16 cm in size were made, according to GOST 30744-2001, and physicomechanical properties were determined.
The CWD composition was optimized using the method of mathematical design of the experiment given in the literature [7], [8], [9].

III. RESULTS AND DISCUSSION

In our studies, the determination of the rational composition of the CWD, the identification of the optimal number of constituent components, and the establishment of an analytical relationship between these factors and the compressive strength of a binder can be adopted by the D-optimal Box-Benkin plan of dimension K = 3, the feature of which is that, changing three parameters at three levels of variation, it allows you to process data based on mathematical and statistical principles at the same time. Plans of this type provide the smallest dispersion region for parameter estimates and reduce the variance in a given region of the plan [7], [8], [9]. In addition, they have the smallest determinant of the covariance matrix and the ratability property, which ensures the selection of matrix points with the same accuracy of predicting the values of the response function, regardless of the direction of the study.

Preliminary experiments revealed that the studied dependence should be described by a quadratic equation of the type:

$$Y=b_0+b_1X_1+b_2X_2+ b_{12}X_1X_2+b_{11}X_{11}++b_{22}X_{22n} \quad (1)$$

where Y is the response function;
b_0, b_1 ... b_{22} - regression coefficients;
X_1, X_2 - studied factors.
As the parameter for optimizing the composition of the CNV was adopted mechanical compressive strength:
- for samples hardened in vivo at the age of 7 and 28 days;

As variable factors of variation, we used the parameters that have the greatest influence on the properties of the obtained material, namely:
X1 - the amount of sand dune (or ETF slag) by weight of the binder, %;
X2 is the amount of superplasticizer, %;
Ranges of variation were adopted based on the results of preliminary studies. As a result of the studies, the strength of the binder stone was determined.
The mass of gypsum stone was assumed constant i.e. 3% by weight of the binder.
Grinding was carried out to obtain a specific surface area of 500 m^2 / kg.
The intervals of variation of variable factors and the experimental design are shown in table 2.

Table II. Design conditions for the experiment on a coded scale

Factors		Units	Conditions of variation			
Natural look	Coded view		Levels			Step
			Lower (-1)	Primary (0)	Upper (1)	
When using sands dune						
Sands dune	X1	%	20	35	50	15
Megaplast-JK 02	X2	%	0,6	1,0	1,4	0,4
When using ETF slag						
ETF slag	X1	%	20	35	50	15
Megaplast-JK 02	X2	%	0,6	1,0	1,4	0,4

The calculation of the coefficients of the regression equation, errors in their determination, as well as the assessment of their significance, was carried out using regression analysis methods.
To carry out the experiment, a series of CNV samples was made according to the conditions of the experimental design.
The manufactured samples were kept under the same conditions for 7 and 28 days, after which their physical and mechanical characteristics were determined. The calculation of the coefficients of the regression equations is performed using the MS Excel program.

Based on the results of the implementation of the experimental design and subsequent mathematical processing of the results, adequate regression equations are obtained that express the mathematical dependences of the strength of binders.

After carrying out mathematical calculations and checking the adequacy, the equation of regression of the strength of the CNV hardened under natural conditions is as follows:

- when using sand dune:

in a 7-day hardening period:

$$Y = 40{,}620 - 19{,}51X_1 + 2{,}38X_2 + 3{,}97X_1^2;$$

in the 28-day hardening period:

$$Y = 40{,}87 - 19{,}76X_1 + 2{,}23X_2 + 4{,}83X_1^2;$$

- when using ETF slag:

in a 7-day hardening period:

$$Y = 63{,}73 - 24{,}2X_1 + 0{,}473X_2 - 1{,}72X_1^2;$$

in the 28-day hardening period:

$$Y = 63{,}78 - 24{,}534X_1 + 0{,}523X_2 - 0{,}277X_{12} - 1{,}454X_1^2 + 0{,}246X_2^2;$$

A comparison of the experimental and theoretical parameters determined from the dependences with the substituted values of the coefficients bi showed their good convergence.

Analyzing the obtained equations, it can be noted that the conclusions obtained for similar functions of the CVD response are valid for them.

The difference lies in the presence of a sign of a more significant effect of the flow of the alumosilicate component of the base metal.

The analysis of the results of mathematical models was performed by the graph analytical method. For this, graph analytical dependences of the strength of the CVD on varied factors in physical quantities were constructed (Figs. I and II).

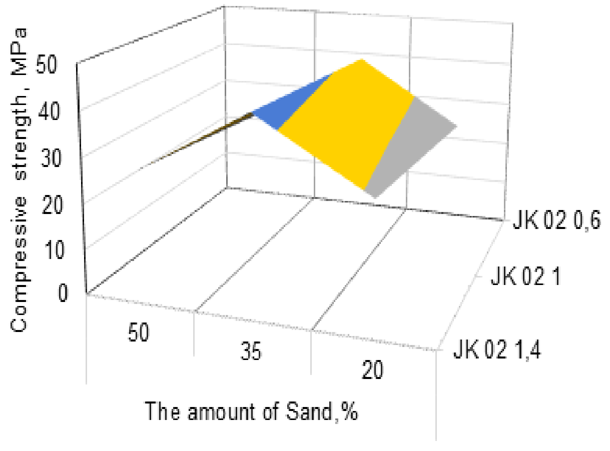

Fig. 1. The effect of the amount of sand dune and superplasticizer on the mechanical strength of the CVD

As a result of statistical and technological analysis of the obtained mathematical models, it was found that the most significant factor affecting the strength of the CVD is the consumption of the mineral component, which turned out to be the largest in absolute value.

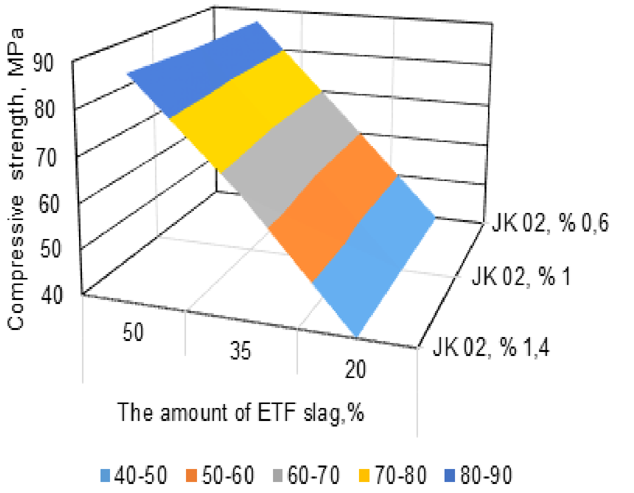

Fig. II. The effect of the amount of sand dune and superplasticizer on the mechanical strength of the CVD

The less significant factor affecting the strength was the content of the chemical additive, since the absolute value of this factor was the least.

IV. CONCLUSION

As a result of studies, replacing Portland cement clinker with sand dune up to 35%, we obtained CVDs with a strength of 43.0 MPa.

Replacing Portland cement clinker up to 50% witch ETF slag made it possible to obtain a CVD with a strength of 88 MPa.

Laboratory studies and analysis of mathematical models found that the developed binder compositions under natural conditions are intensively gaining their strength in the initial hardening period (7 days), and in the further hardening up to the 28-day hardening period their strength increases slightly.

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