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USE OF BOTTOM ASH WASTE OF A THERMAL POWER PLANT FOR PRODUCING A CONSTRUCTION BINDER

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ABSTRACT

Efficient and rational use of ash and slag waste from a thermal power plant for the production of building binders is primarily determined by their quality properties, as well as the technology used and its optimal parameters. This article is devoted to solving these issues. The results obtained showed that ash and slag from the TPP of SSGPO JSC (Rudny, Kazakhstan) are effective materials for obtaining slowly hardening and cement-containing binders from them, used for the construction of the bases of road pavements. To study the physical and mechanical properties of binders, samples of 10x10x10 cm were made, hardened for 28 days under normal conditions. It has been established that the cement-ash-and-slag binder with the addition of 20 to 50% ash and slag has an activity of 25-37 MPa, and in terms of efficiency, as a binder, it surpasses the slowly hardening ash-and-slag binder. On the basis of a cement-ash and slag binder, it is possible to make a concrete mixture for the construction of the bases of road pavements of any category (the ratio between SHGPS: TsZShV can be 1: 5; 1: 4; 1: 3; 1: 2; and 1: 1). In this case, the strength of the bases can vary from 2.8 ... 14 MPa (for a mixture of 1: 5 composition) to 9 ... 17 MPa (for a mixture of 1: 1 composition). To determine the optimal parameters of the developed technology for producing a cement - ash and slag binder, a methodical approach based on probabilistic-deterministic planning of the experiment was used. In accordance with the plan of the experiment, 16 laboratory experiments were carried out to obtain cement-ash-and-slag binders, for each of which the mobility of the cement-ash and slag test was determined. From the obtained binders of various compositions, samples-beams with a size of 4x4x16 cm were also made, which, after holding for 28 days under normal conditions, were tested for bending and compression. It has been established that the optimum technology indicators are achieved when the cement content in the ash-and-slag mixture is 50%, the mixing time of the dry mixture is 9 minutes, the water-binding ratio is 0.35, and the mixing time of the wet mixture is 5 minutes. At the same time, the binder of optimal composition has sufficient strength after 28 days of hardening, allows to reduce cement consumption and provides increased homogeneity and mobility of mixtures in dry and wet state, which facilitates technological processes for preparing hardening systems (bending strength - 4.7 MPa; compressive strength - 34.4 MPa and the mobility of the cement-ash and slag test is 4.5 cm).

Keywords: ash and slag waste, properties, cement, binder, technology, parameters, optimization.

INTRODUCTION

To obtain the necessary heat and electric energy, the mining enterprises of Kazakhstan often use their own thermal power plants (TPP). Many of them run on coal, the combustion of which produces a large amount of ash and slag waste. So, for example, in the ash dumps of the TPP of SSGPO JSC (Rudny, Kazakhstan) over 40 years of operation, more than 10 million m^3 of ash and slag have been accumulated. At the same time, the annual amount of generated ash and slag waste (ASW) is currently about 800 thousand tons. The storage of ash and slag waste leads not only to the seizure of significant land areas, but also causes a very significant pollution of almost all environmental components in the area of their location. The level of use of ash and slag by the domestic industry is insignificant. Analysis of the experience of using ash and slag waste abroad has shown that there are numerous technologies for their processing, and the level of utilization can reach 70 - 90% of the annual output [1-5]. At the same time, the predominant direction of research on obtaining building materials is associated with the use of fly ash.

MATERIALS AND METHODS

To obtain a construction binder, ash and slag from the TPP of SSGPO AO were used, characterized by the following phase composition,%: quartz - 23.0, mullite - 5.0, glass - 66.0, coal - 6.0. The second component was Portland cement, grade PC 500 D0N, with the following phase composition,%: C3S (alite) - 44.12; β-C2S (belite) - 31.28; C4AF (celite) 13.96; C3A (felite) - 3.47. Crushed stone for the construction of road bases met the technical requirements of GOST 25607-2009 “Crushed stone-gravel-sand mixtures for coatings and bases of highways and airfields. Technical conditions "and ST RK 1225-2019" Mixes asphalt road, airfield and asphalt concrete. Technical conditions ". For the study of an independent slowly hardening binder, samples of 10x10x10 cm were made, prepared from crushed stone-gravel-sand mixture, ash and slag and water at their ratios of 70:20:10 (mixture: ash and slag: water) and hardened for 28 days under normal conditions. The activity of cement-ash and slag binders based on cement grade PC 500 DON was determined in accordance with GOST 310.4-81 “Cements. Methods for determining ultimate strength in bending and compression”. For the study of the cement - ash and slag binder, concrete samples of 10x10x10 cm in size were prepared, hardened under normal conditions with a moisture content of over 95% (humid environment) for 28 days.

To determine the optimal parameters of the technology for producing a cement - ash and slag binder, a methodical approach based on probabilistic-deterministic planning of the experiment was used [6]. The methodology includes: determination, based on the analysis of the technology under study, of its input parameters and the ranges of their variation; identification of output controlled functions from these parameters; construction of a matrix of multifactorial and multilevel planning of the experiment. The experimental values of each of the output functions are used to determine their particular dependencies on the input parameters. On the basis of partial approximated functions according to the formula of M.M. Protodyakonov, generalized equations of the dependence of the output functions on the input parameters are obtained:

$$Y_{\Pi} = \frac{\prod_{i=1}^{n} Y_i}{Y_{cp}^{n-1}} \tag{1}$$

where Yп- generalized function, Y_i - private function, $\prod_{i=1}^{n} Y_i$ product of all private functions, Ycp - the total average of all considered values of the generalized function to the degree, one less number of partial functions.

In accordance with the plan of the experiment, 16 laboratory experiments were carried out to obtain cement-ash-and-slag binders, for each of which the mobility of the cement-ash and slag test was determined. From the obtained binders of various compositions, samples-beams with a size of 4x4x16 cm were also made, which, after holding for 28 days under normal conditions, were tested for bending and compression. The specimens are first tested for bending and then the halves for compression. The flexural strength was determined on an MII-100 testing machine. The halves of the beams obtained after the bending test were subjected to compression tests on a PGM-500MG4 hydraulic press.

RESULTS AND DISCUSSIONS

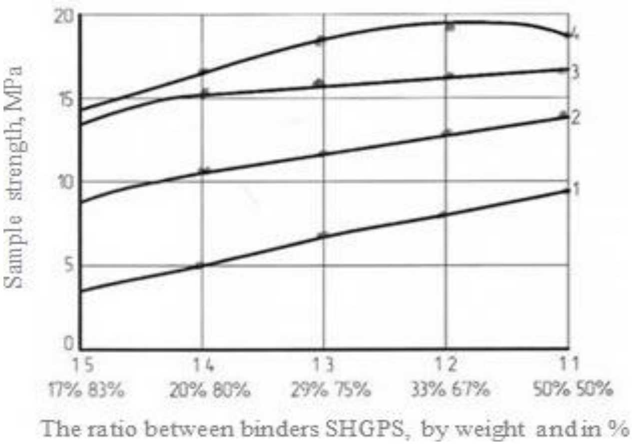
Our earlier studies of the physicochemical and hydration properties of ash and slag from TPPs of JSC SSGPO found that one of the promising directions of their utilization is the use in the composition of binders to create the foundations of highways [7]. Ash and slag can be used in mixtures for the formation of layers of the bases of highways, as an independent slowly hardening and cement-ash and slag binders.

When using ash and slag as an independent slowly hardening binder (in fact, a filler) to increase activity, cement (4-5%) or lime (6-8%) is added to its composition. Tests of the samples made it possible to obtain the following physical and mechanical indicators:

- ultimate compressive strength of water-saturated samples at the age of 28 days. reaches 2.0 ... 3.0 MPa;
- ultimate strength in compression of water-saturated samples after testing for frost resistance: 1.5 ... 2.5 MPa;
- ultimate tensile strength in bending of water-saturated samples at the age of 28 days: 0.4 ... 0.5 MPa;
- coefficient of frost resistance at the age of 90 days: 0.80.

It should be noted that the base on an independent slowly hardening binder with low physical and mechanical properties will have a reduced crack resistance, frost resistance and durability. This is due to the shrinkage of the bases during hardening, significant temperature stresses during daily and seasonal temperature changes and a small amount of the activating component of the ash and slag binder - cement. In cement-ash and slag binders (TsZShV), cement plays a dominant role, and ash and slag is used as an additive, while its content in the mixture varies from 20 to 50%. It was found that the activity of TsZShV depending on the content of ash and slag was, MPa: binder with 20% ash and slag - 37; astringent with 30% ash and slag - 35; a binder with 40% ash and slag - 30 and a binder with 50% ash and slag - 25. The data obtained show that with an increase in the cement content, the activity of the ash and slag binder increases, and, conversely, an increase in the ash and slag leads to a decrease in the activity of the binders.

Obviously the strength of the bases, all other things being equal, depends on the ratio between the crushed stone-gravel-sand mixture (SCHGPS) and TsZShV. The dependence of strength on the ratio between SHGPS and TsZShV (by weight and in%) is shown in Figure-1.



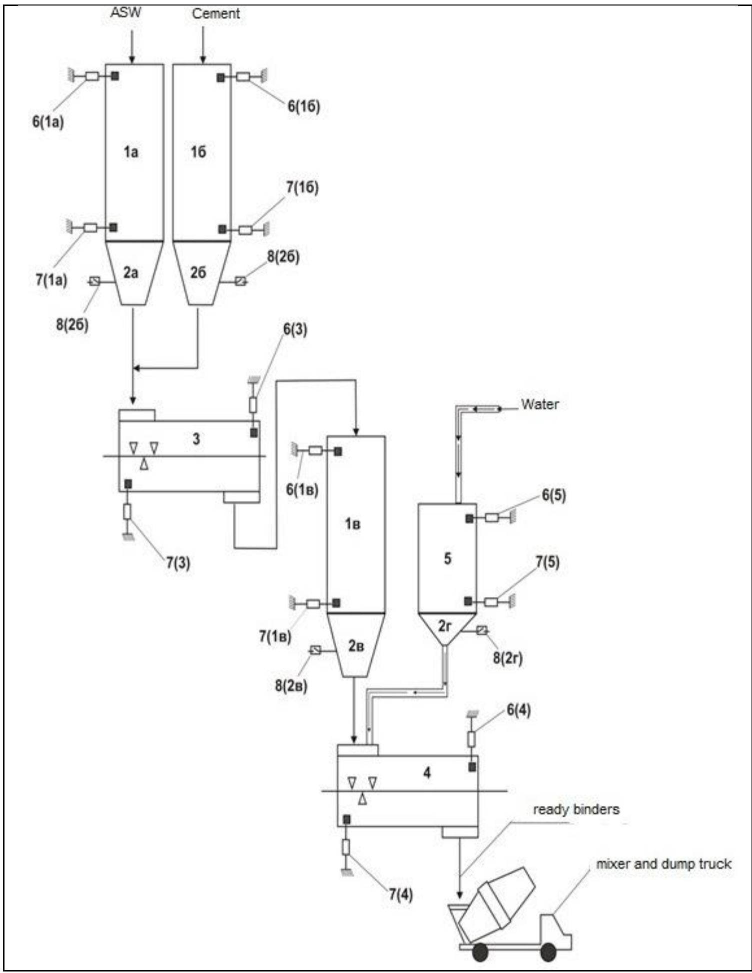
1 - binder with an activity of 25 MPa; 2 - binder with an activity of 30 MPa;
3 - binder with an activity of 35 MPa; 4 - binder with an activity of 37 MPa

Figure-1. Change in the strength of samples depending on the ratio between SHGPS and TsZShV.

Figure-1 shows that the strength of the samples, depending on the ratio of ShGPS: TsZShV, is in the range of 2.8 ... 17 MPa, while with an increase in the activity of TsZShV and with an increase in its content, the strength of concrete increases;

Comparison of the results on the activity of independent slowly hardening ash-and-slag and cement-ash-and-slag binders shows that when building the foundations of highways, TsZShV should be preferred since it has incomparably higher activity, therefore, the base based on it has higher indicators of crack resistance, frost resistance and durability.

The composition and properties of ash waste determine the ways of their use and create prerequisites for the development of a raw material base of nonmetallic materials. Therefore, the development of technologies using ash and slag waste instead of primary natural resources is cost effective and helps to reduce the level of environmental pollution. The technology for producing a cement-ash and slag binder includes the following operations: loading of receiving bins; dosing of the starting components; preparation of dry mix in a mixer; loading the intermediate hopper with a dry mixture; dosing dry mix and water; preparation of TsZShV in a concrete mixer; unloading of the finished binder. The technological process for the manufacture of TsZShV is presented by the diagram shown in Figure-2.



1a, 1б, 1c - hopper of ash and slag waste, cement and dry mix
2 - dispensers (2a-ASW; 2б-cement; 2в-dry mix; 2г-water)
3 - mixer for dry mixing of materials
4 - mixer for obtaining a wet mixture
5 - service water tank
6 - upper level sensors (6 (1a) -ASW; 6 (1б) -cement; 6 (1c) -dry mix; 6 (3) -dry mixers; 6 (4) -wet mixers; 6 (5) -water)
7 - sensors of the lower level (7 (1a) -ASW; 7 (1б) -cement; 7 (1c) -dry mix; 7 (3) -mixer dry mixing; 7 (4) -mixer wet mix; 7 (5) -water)
8 - open / close sensors. dispensers (2a - ash-and-slag waste; 2б-cement; 2c - dry mix; 2d - water)

Figure-2. Technological scheme for obtaining a cement-ash and slag binder for the foundation of highways.

Cement and homogeneous ash and slag to the technological line, where the binder is prepared, are delivered by a cement truck and fed to the appropriate bunkers (1a and 1b). At the same time, the service water tank (5) is filled. The receiving (1a and 1b) and intermediate (1c) bunkers, as well as the water tank (5) are equipped with sensors showing the maximum (upper sensors) and minimum (lower sensors) level of materials in them. From the bunkers (1a and 1b) through the batchers (2a and 2b) cement and ash and slag in specified proportions enter the mixer (3), in which dry mixing takes place. At the same time, the mixer level sensors (6 and 7) are synchronized with the dispenser sensors 8 (2a) and 8 (2b), which contributes to the continuous operation of the dry mixing mixer. The resulting dry mixture is pumped into the intermediate hopper (1c), from where it enters the concrete mixer (4) through the batcher (2c), where it is mixed with water from the tank (5) through the batcher (2g) in certain proportions. Further, in the process of mixing, a cement-ash and slag mixture with a certain mobility is obtained. The finished binder is delivered to the facility on a mixer (or on a dump truck), where it is mixed on the road with a gravel-sand mixture in specified proportions, after which the base is laid layer by layer on the prepared subbase.

To optimize the parameters of the technology for the production of CZShV, the following input parameters (factors) were identified: X1 - cement content in the mixture,% of the total mass; X2 is the time of mixing the dry mixture, min; X3 - water-binding ratio; X4 is the time of mixing the wet mixture, min. The output controlled functions of the technology are: Yp - the mobility of the cement-ash and slag test (cone draft, cm); Yi - bending strength, MPa; Yc - compressive strength, MPa.

The ranges of the input parameters are shown in Table-1.

Table-1. Levels of the investigated factors.

Factors	**Levels**			
	1	**2**	**3**	**4**
X_1	20	30	40	50
X_2	5	7	9	11
X_3	0,25	0,30	0,35	0,40
X_4	3	4	5	6

Further, a matrix of 4-factor planning of the experiment at 4 levels was formed (Table-2).

Table-2. Matrix of 4-factor planning of the experiment at 4 levels.

№, п/п	X_1	X_2	X_3	X_4	$Y_{\text{п}}$	$Y_{\text{и}}$	$Y_{\text{с}}$	$Y_{\text{пп}}$	$Y_{\text{ип}}$	$Y_{\text{сп}}$
1	20	5	0,25	3	0,5	0,8	5,3	0,99	0,84	6,08
2	30	7	0,30	4	2,0	1,2	11,1	2,08	2,11	14,68
3	40	9	0,35	5	4,0	4,6	21,7	3,84	3,38	23,29
4	50	11	0,40	6	6,5	4,6	27,2	6,94	4,65	31,89
5	20	7	0,35	6	1,5	1,0	5,68	1,80	0,84	6,08
6	30	5	0,40	5	3,5	1,8	14,5	3,18	2,11	14,68
7	40	11	0,25	4	2,5	3,9	25,1	2,30	3,38	23,29
8	50	9	0,30	3	4,5	4,7	34,4	4,13	4,65	31,89
9	20	9	0,40	4	2,0	1,3	8,3	1,72	0,84	6,08
10	30	11	0,35	3	3,0	1,9	15,2	2,72	2,11	14,68
11	40	5	0,30	6	3,5	3,9	27,3	3,68	3,38	23,29
12	50	7	0,25	5	3,0	5,0	34,4	3,16	4,65	31,89
13	20	11	0,30	5	1,3	1,1	7,6	1,25	0,84	6,08
14	30	9	0,25	6	2,4	1,4	12,4	2,00	2,11	14,68
15	40	7	0,40	3	4,0	2,5	22,3	4,60	3,38	23,29
16	50	5	0,35	4	4,7	4,0	31,2	4,72	4,65	31,89

16 laboratory experiments were carried out to obtain TsZShV, for each of which the values of the output functions Yp, Yi and Yc, given in Table-2, were determined. Based on the obtained parameter values from Table-2 of the experimental partial functions and their approximation by the least squares method, the calculated quotients functions from input parameters. For the mobility of the cement-ash and slag test, these dependencies have the form:

$$y_1 = 0{,}1082x_1 - 0{,}727;$$
$$y_2 = 0{,}331x_2^2 - 0{,}46x_2 + 4{,}45;$$
$$y_3 = 12{,}34x_3 - 0{,}953;$$
$$y_4 = 0{,}18x_4^2 - 1{,}46x_4 + 5{,}76$$

The graphs obtained from the calculated dependencies of the partial mobility functions are shown in Figure-3. Checking each of the functions for significance showed that the particular dependencies of the mobility of the cement-ash slag dough on the cement content in the mixture, the water-binding ratio and the duration of mixing the wet mixture are significant.

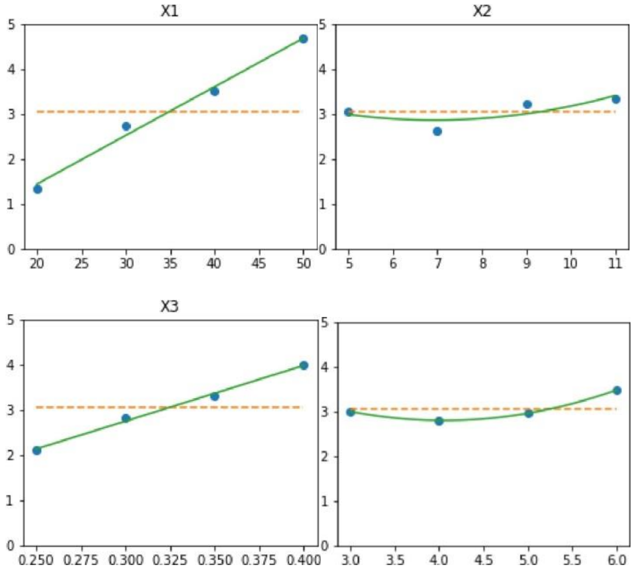


Figure-3. Curves of approximation of the dependences of the partial functions of the mobility of the cement-ash slag test on the input parameters (X1, X2, X3, X4).

The generalized function of the mobility of the cement-ash slag test from the input parameters, determined by the formula (1), has the form:

$$\text{Ypp} = \frac{(0{,}1082\mathrm{x}_1 - 0{,}727) * (12{,}34\mathrm{x}_3 - 0{,}953) * (\, y_4 = 0{,}18x_4^2 - 1{,}46x_4 + 5{,}76)}{3{,}06^2};$$

Generalized function of flexural strength from input parameters:

$$\mathrm{Y_{ip}} = 0{,}1271x_1 - 1{,}711;$$

Generalized function of compressive strength versus input parameters:

$$\mathrm{Ysp} = 0{,}8604x_1 - 11{,}13;$$

The calculated values of the indicators of the mobility of the cement-ash and slag test (Ypp), the flexural strength (Yip) and the compressive strength (Ysp), determined from the generalized dependencies, are given in Table-2.

The choice of ZZShV with the optimal composition is significantly influenced by: technical requirements for roads, physical, mechanical and granulometric properties of the future aggregate - sand and gravel mixture; technical requirements for sealing specified in the project, etc. In this case, the strength of the samples obtained from the binder should be: bending - more than 4.0 MPa; for compression - more than 20.0 MPa, and the mobility of the cement ash and slag test should be (3.5-4.5 cm). Therefore, experiment No. 8 should be considered optimal (with input parameters: X1 = 50.0; X2 = 9.0; X3 = 0.35; X4 = 5.0), compression 4.7 MPa and 34.4 MPa, respectively.

CONCLUSIONS

The results obtained showed that ash and slag from the TPP of SSGPO JSC are effective materials for obtaining slowly hardening and cement-containing binders from them, used for the construction of the bases of road pavements. It has been established that the cement - ash and slag binder with the addition of 20 to 50% ash and slag has an activity of 25-37 MPa, and in terms of efficiency, as a binder, it surpasses the slowly hardening ash and slag binder. On the basis of TsZShV, it is possible to make a concrete mixture for the construction of the bases of pavements of any category (the ratio between SHGPS: TsZShV can be 1: 5; 1: 4; 1: 3; 1: 2; and 1: 1). In this case, the strength of the bases can vary from 2.8 ... 14 MPa (for a mixture of 1: 5 compositions) to 9 ... 17 MPa (for a mixture of 1: 1 composition). Optimization of the parameters of the developed technology for the production of CZShV showed that the binder of optimal composition has sufficient strength after 28 days of hardening, allows to reduce cement consumption and provides increased homogeneity and mobility of mixtures in dry and wet state, which facilitates technological processes in the preparation of hardening systems (bending strength - 4.7 MPa; compressive strength - 34.4 MPa and mobility of cement-ash and slag test - 4.5 cm). The developed technical solutions for obtaining slow-hardening and cement-containing binders make it possible to create low-waste technologies using ash and slag from the TPP of SSGPO JSC, contribute to the rational distribution of mineral resources and solve environmental issues.

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