Article

Modern trends in the development of the construction industry in the production of building materials

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Abstract. The paper describes the technology of manufacturing a construction product by vibrocompression using ash and slag waste from thermal power plants in the Pavlodar region. The task of the experimental research was to obtain a hollow wall stone based on ash and slag waste with a strength grade that is not inferior to products made according to the traditional recipe. A study was carried out with selected samples of bauxite sludge from the sludge dumps of the Pavlodar Aluminum Plant, as fillers was used metallurgical slag of fractions 0-5 and 20-30 according to 6 recipes made in forms 100x100x100 mm. The obtained samples with different ratios of components in the mixture were investigated for compressive strength, moisture absorption, frost resistance. It has been established that when ash and slag waste are added to the composition of the concrete mixture in an amount of up to 35 % of the mass of dry components, the strength characteristics of the hollow wall stone correspond to the selected brand.
Keywords: slag, ash, waste, development of the construction, industry, building materials, concrete mix.

1. Introduction

Currently, in the Republic of Kazakhstan in dumps, according to reports of independent assessments [1-2], more than 400 million tons of ash and slag waste from thermal power plants and metallurgical waste have been accumulated, which is an aggravation of the environmental situation in industrial regions and requires the development of technical solutions to improve it [3].

One of the scientific and technical solutions to this problem, which is also essential for the construction industry, is the production of construction products using industrial waste in the concrete mixture. Utilization of large-tonnage industrial waste confirms the relevance of the development of this issue and, in parallel, is strengthened by the implementation of large-scale State programs to increase the affordability of housing, mortgage lending, which ensures a stable growth in demand for construction products and, as a result, raw materials for their manufacture [4].

A promising raw material for the production of building products is ash and slag waste from thermal power plants and waste from the metallurgical industry [5-6]. In addition, today the scaling of the technology for the production of heavy concrete using ash and slag waste from thermal power plants and waste from metallurgy of the Republic of Kazakhstan is widely used [1-7].

LLP «EcostroyNII-PV», organized under the grant program «Stimulating productive innovations» from the Ministry of Education and Science of the Republic of Kazakhstan and the World Bank (Subproject № APP-SSG-17/0290F), uses ash and slag and metallurgical waste as a basis for the manufacture of building products: ash from the TPP of Pavlodar and Aksu TPP of JSC «Eurasian

Energy Corporation» (EEC, ERG) based on Ekibastuz coal, slimes of the Pavlodar aluminum plant of JSC «Aluminum of Kazakhstan», steel-making slags of Pavlodar steel-making factories PF LLP «Casting», PF LLP «KSP Steel».

2. Methods and Materials

The development of new compositions of concrete mixtures with improved performance characteristics using ash and slag waste from thermal stations and metallurgical enterprises of Pavlodar region as aggregates and binder requires a large number of experiments with varying the percentage of all components that make up concrete mixtures, establishing the regularity of the effect of various additives on physical and mechanical characteristics of mixtures [8].

Expansion of the raw material base of ash and slag waste allowed us to make samples using recipes, which include ashes of the above-mentioned TPP.

Table 1- Chemical composition of fly ash from Pavlodar TPP-1 in %.

SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	MnO
60.6	28.6	1.4	5.4	2.0	0.5	0.5	0.2	0.7	0.1

The fly ash used in our technological process (Figure 1) is characterized by a fine granular fraction [9-10]. According to GOST 25818-91 and 25592-91, the content of calcium oxide CaO in the ash component of the ash and slag mixture and in the fine-grained mixture should be no more than 10 % by weight. The content of magnesium oxide MgO in the ash component of the ash and slag mixture and in the fine-grained mixture should be no more than 5 % by weight [11-12]. The content of sulfurous and sulfuric acid compounds in terms of SO3 in the ash and slag components of the ash-and-slag mixture should be no more than 3 % by mass, including sulfide sulfur – no more than 1 % by mass. The content of alkaline sodium and potassium oxides in terms of Na2O in the ash component of the ash and slag mixture and in the fine-grained mixture should be no more than 3 % by weight [13].

Figure 1 – Fly ash of Pavlodar TPP-1

Bauxite sludge from the Pavlodar Aluminum Plant is a by-product of the production of alumina A2O3. The currently known methods for the production of alumina can be divided into electrothermal, acidic and alkaline. It is possible to convert the alumina contained in the raw material into sodium aluminate in various ways, one of which is the «Dry» process (Bayer sintering process) or simply «Sintering» (the so-called Mueller-Jakovin process). Ore with alkali metal salts is sintered in rotary kilns, then the aluminate is leached, and the resulting aqueous solution is subjected to decomposition. The composition of the concrete mixes included bauxite sludge from the Pavlodar Aluminum Plant (Figure 2a, 2b, 2c), of various fractions, sifted into a sieve with cells from 0.05 to 2 mm [14].

Table 2 − Chemical composition of bauxite sludge from Pavlodar Aluminum Plant, obtained by Bayer sintering

Fe_2O_3	Al_2O_3	CaO	SiO_2	TiO	CO_2	Na_2O	MgO
27-33	4.0-5.0	39-44	19-21	2.0	0.8-1.0	0.9-1.5	0.3-1.2

In appearance, bauxite sludge (Figure 2a) is medium-grained beige-brown sand with inclusions of easily crumbling lumps of various sizes. The moisture content of bauxite sludge samples should be within 20-30 %, density – 2.6 - 2.86 g/cm^3, bulk density in a loosened state - from 1.1 to 1.3 g/cm^3.

Figure 2 − Bauxite sludge: a) from the Pavlodar Aluminum Plant; b) fraction 0.63; c) fraction 0.4

For the research, representative samples of bauxite sludge were taken from the sludge dumps of the Pavlodar Aluminum Plant. Sludge samples were taken in accordance with the requirements GOST 12071-2014. Statistical processing of the research results was carried out in accordance with the «Recommendations for the use of bauxite slimes of alumina production in concrete and mortars» NIIZhB Gosstroy USSR 1990.

Metallurgical slag of fraction 0-5 (Figure 3a) and coarse fractions 20-30 (Figure 3b) were used as fillers.

Figure 3 - Metallurgical slag: a) fraction 0-5; b) fraction 20-30

The slag is gray, a porous microstructure is observed, the presence of a crystallized glassy component is noted [15–17]. Brown inclusions indicate the presence of iron oxide. The chemical composition of the slag PF LLP «Casting» (Table. 3). Depending on the formulation, the above-described technogenic raw materials were included in the composition of the concrete mixture as aggregates and binder [18]. For each recipe, 6 samples were made (Figure 4), which were placed in molds (Figure 5) 100x100x100 mm in accordance with GOST 25781-81, the samples (without steaming) were stored at room temperature for 28 days, after which strength tests were carried out with them (Figure 6-7).

Table 3 − Average chemical composition of slag in EAF ESPC PF «Casting» LLP and PF «KSP steel» LLP for 2019, %

Fe	SiO$_2$	Al$_2$O$_3$	CaO	MgO	MnO	S	imp.	Σ
28-35.9	12.1-18.9	1.9-4.8	21.1-24.6	6.9-20.2	5.1-8.2	0.03-0.04	1.2-1.7	90.0-98.3

Figure 4 − Test pieces

Figure 5 − Forms 100x100x100 mm in accordance with GOST 25781-81

Figure 6 − Test for the strength of the sample

Figure 7 − Destruction of the sample

Figure 8 − Indication of strength values for sample № 17-5

Figure 9 - Compression of a hollow wall stone

As a result of experiments, it was revealed that:

- Ashes of Pavlodar TPP, used as a filler, do not affect the decrease in the strength of the concrete mixture. Due to its low activity (when grinding ash to a size of 0,0005), it can be used as a replacement for clinker, which is not practical on an industrial scale. The use of ash up to 15 % of the amount of cement does not affect the decrease in strength indicators and can be used as an aggregate to replace sand.

- The use of bauxite sludge with the addition of milk of lime made it possible to increase the strength of concrete specimens up to the M50 grade, class B3, 5, taking into account the absence of vibropressing. Formulation development using bauxite sludge continues.

- The use of metallurgical slag of fraction 0-5 as a filler did not affect the strength of the samples due to the absence of vibrocompression and a steaming chamber, due to which the cement adhesion process was low. At the same time, hollow stones made with metallurgical slag on the Rifey-Udar-SDA production line showed class B7.5 (M100), but the stones turned out to be heavy (27 kg).

To date, 33 recipes for concrete mixtures have been developed using various fillers, additives and binders. It should be noted that the process of vibrocompression on the Rifey-Udar-SDA line makes it possible to obtain the strength of products in a short time. For example, a sample made according to recipe № 17 received a strength almost similar to the prototype after 7 days (Figure 8 and 9).

Based on the results of the tests, the compositions of concrete were selected using ash and slag waste (Table 4).

Table 4 – Results of testing concrete samples using ash and slag waste

Sample brand	Mass fraction of cement, (%)	Strength, kg/cm^2	Strength, MPa	Concrete strength class	Concrete strength grade	Density, g/cm^3
Z0040-vt	40	243.8	23.9	B23	M300	2.09
Z1035-vt	35	175.0	17.2	B17	M200	1.90
Z2030-vt	30	163.3	16.0	B16	M200	1.76
Z3025-vt	25	88.3	8.7	B8	M100	1.64
Z4020-vt	20	36.1	3.5	B3.5	M50	1.59
Z0040-vt	40	386.0	37.9	B30	M400	2.59
Z1035-vt	35	329.0	32.3	B25	M350	2.37
Z2030-vt	30	309.0	30.3	B25	M350	2.17
Z3025-vt	25	236.6	23.3	B20	M250	1.98
Z4020-vt	20	212.2	20.8	B15	M200	1.88

Note: vt – vibrating table (sample obtained on a vibrating table); vp – vibropressing (industrial design)

Based on the tests of samples using ash and slag waste from Pavlodar TPP-1, it was found that there are reserves for saving cement when using ash in the case of preparing industrial samples by vibrocompression; to adjust the composition of concrete, it is required to conduct pilot tests of products under the combined action of vibration and pressing.

On the technological line «Rifey-Udar-PU-SDA» were made industrial samples of stone wall hollow composition Z4020 (table 4). Tests have shown concrete class B15. After reducing the amount of cement, tests showed the concrete class – B3, 5 (M50), which is sufficient for the construction of low-rise buildings. The same composition was used to make «Partition stone 390x120x188 mm». The strength of the stones was also obtained B3, 5 (M50). Since this strength is not required for the material of the baffles, it is possible to reduce the consumption of cement. After laboratory tests, it was decided to investigate the use of ash and slag waste from Pavlodar TPP in industrial and field tests.

2. Industrial and full-scale tests of the construction product

Industrial and full-scale tests of the construction product «Four-hollow wall stone, type SKT-1, using ash-and-slag waste»:

- Product «Wall stone four-hollow four-hollow SKSH-1 with ash» − product size: 390×188×190 mm.

- *Test object:* one-story extension to the office building of the workshop on the territory of the production site of EcostroyNII-PV LLP (Figure 10).

Parameters of the object of full-scale tests: length − 3 m, width − 2.7 m, height − 2.5 m, wall thickness − 190 mm.

The object of full-scale tests was made on a strip prefabricated concrete foundation; the laying of four-hollow wall stones was carried out with a cement-sand mortar of a ratio of 1:3.

The number of products for the construction of a full-scale object: Wall stone four-hollow hollow with the use of ash-and-slag waste − 300 suitable artificial stones. The building is covered with plates PK 3x1,5 − 2 pcs.

Location of the object of full-scale tests: Pavlodar, central industrial region.

The purpose of carrying out full-scale tests: Research of the behavior of four-hollow wall stones based on ash and slag waste in natural operation (weight, wind, rain and snow load) in a moderately aggressive environment in order to assess the suitability of EcostroyNII-PV products for further use by consumers while ensuring safety conditions and functional load on products.

Figure 10 − Full-scale tests of the manufactured pilot-industrial batch of products «Hollow wall stone with ash-and-slag waste» in the form of construction of an extension to the production workshop of EcostroyNII-PV LLP

The composition of the raw mixes used for the manufacture of products is shown in Table 5 [19]

Table 5 − Composition of raw mixes for the manufacture of hollow wall stones

Component name and characteristics (granulometry)	Quantity
Natural sand for construction work of Pavlodar River Port JSC, size group - medium, GOST 8736-2014.	15-20 %
Ash and slag waste from TPP-1 of JSC Aluminum of Kazakhstan, GOST 25592-91. Ash and slag mixtures of thermal power plants for concrete. Technical conditions.	30-35 %
Screening crushing of dense rocks for construction work, LLP «Asphalt concrete», deposit «Maikinskoe» GOST 31424-2010.	35-40 %
Portland cement Premium 450 CEM II/A-Sh 32.5N (Semey cement plant production company LLP) GOST 31108-2016.	9-13 %
Water-cement ratio (GOST 23732-2011 Water for concrete and mortars. Specifications).	0.16-0.2
Additive Solitard S3, TU 20.59.59-001-16918243-2018 LLC «Bentax», Novosibirsk − 0,4-0,6 % by weight of cement.	0.4-0.6 % by weight of cement

3. Results and Discussion

The mechanical characteristics of the products were preliminarily determined by the destructive method using a PMG 1000MG4 hydraulic press in an amount of 5 % of each batch of products. Water absorption of stones was determined according to GOST 12730.3-78 «Concrete. Method for determining water absorption». 5 selected product samples were tested. The test results are shown in Table 6.

Table 6 − Test results

Indicator name	Sample № and marking				
	1	2	3	4	5
Weight, kg	18,5	18,7	19,4	19,0	19,8
Ultimate strength, MPa/concrete class	3.6/B2.5	3.3/B2.5	3.8/B2.5	3.2/B2.5	3.8/B2.5
Water absorption, %	5,.0	4.8	4.7	4.2	3.8

4. Conclusions

Based on the results of industrial tests, the following conclusion was obtained:

1. The produced artificial stones in their mechanical characteristics correspond to the class of concrete B2.5.

2. During the period of observation the object of full-scale tests within one year, the object was subjected to weight, wind, rain and snow loads.

3. The water absorption of products did not exceed 5 %, which corresponds to the standard indicators. Destruction of the object, cracks on the surface, delamination, chips were not observed, the object corresponds to its functional characteristics.

4. It is recommended to apply the recipe for the composition and production technology of hollow wall stones using ash and slag waste for the use of these products in low-rise construction.

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