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Lightweight structural thermal insulation concrete using TPP ash

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ABSTRACT
The article presents the results of developing lightweight structural concretes based on ash-slag waste from the Almaty Thermal Power Plant-2. The ash-slag aggregates were produced using both firing and non-firing (clinker) technologies. The fired aggregates, obtained with the use of bentonite clay, exhibited a bulk density of 530–640 kg/m³ and a strength of 1.8–4.8 MPa. The non-fired aggregates based on Portland cement had a density of 644–690 kg/m³ and a strength of 1.79–2.98 MPa, while those based on liquid glass showed a density of 562–642 kg/m³ and a strength of 1.93–3.8 MPa. Using the obtained aggregates, lightweight concretes with a density of 1210–1750 kg/m³ and a strength of 100–152 kg/cm² were produced, meeting the requirements of GOST 25820-2014. In the compositions without coarse aggregate, the influence of additives such as $CaCl_2$, superplasticizers, and basalt fibers on the properties of ash concrete was studied. The strength of the concrete after 28 days exceeded the 7-day strength by 1.5–2.3 times, with the most significant effect observed from $CaCl_2$. Ash concrete of classes B10–B12 with a density of 1500–1600 kg/m³ was obtained, which according to GOST can be classified as structural-thermal insulating concrete. The objective of the research is to develop compositions of lightweight structural concrete based on ash-slag waste. The novelty of the work: for the first time, ash-slag aggregates based on the ash-slag from Almaty Thermal Power Plant-2 have been obtained using both firing and non-firing technologies.

Keywords: ash and slag, ash concrete, aggregate, benton clay, firing, hardening, density, strength.

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Introduction

When coal is burned, 10-45% of ash and slag waste (ASW) is produced, which is transported to ash dumps, forming an ash-slag mixture (ASM) [1]. ASW requires significant operational costs and is a source of environmental pollution, posing threats to human health and ecosystems. At the same time, its chemical and mineralogical composition is similar to that of natural raw materials, opening up opportunities for use in industry and construction, thus helping to conserve natural resources [2]. The recycling rate of ASW in Russia is 4-5%, while in developed countries it is around 50-90%, thanks to government support for their utilization [3].

In Germany, 3.1 million tons of cement are replaced annually with ASW. This practice saves resources and energy needed for cement production, as well as recoups costs related to silos, transportation, and salaries [4]. In South Africa, with financial government support, experimental construction of roads using fly ash is being conducted [5]. It has been proven that mixtures of fly ash with inert materials achieve 50-70% of the strength of cement-stabilized materials. The American Coal Ash Association and the Solid Waste Utilization Group sponsor a project to promote the use of coal combustion products in construction [6]. Research is also being conducted on the use of ASW for lightweight aggregates and concretes. A patent for a method of producing lightweight aggregates from carbon-containing waste from thermal power plants includes mixing with additives, pellet formation, and firing. The resulting porous aggregate has a density of 200-300 kg/m³ and a strength of 0.8-1.2 MPa [7].

The study [8] shows that concrete with fired ash gravel is 22% lighter and 20% stronger than conventional concrete, with a drying shrinkage 33% lower. Reducing cement content by 20% does not affect strength. González-Corrochano and co-authors investigated the production of gravel from thermal power plant ash, firing at 1175-1225 °C with a comprehensive analysis [9]. Non-fired ash gravel can be produced from various ashes and ash-slag mixtures, with the addition of hardening accelerators. The strength of non-fired gravel reaches 3-8 MPa with a density of 600-1100 kg/m³ [10]. The study [11] examined the interaction processes of fly ash with liquid glass and calcium chloride, resulting in concrete with strengths of 2.1-10 MPa.

In the research [12], optimal compositions of lightweight concrete with fly ash from the Dnipro Thermal Power Plant were determined: ash consumption of 370-410 kg/m³, cement of 140-180 kg, density of 1720-1780 kg/m³, and compressive strength of 7.3-8.9 MPa. Authors [13] reviewed the physicochemical characteristics of waste for the production of building materials. The study [14] explored the microstructure of pellets made from ash and glass waste. The article [15] presents data on fly ash for the production of fired ash gravel and high-strength concrete (up to 55 MPa). Research [16] is dedicated to porous concrete with fired ash gravel, showing strengths of 7.15-15.74 MPa and water permeability of 9.38-16.07 mm/s.

The work [17] investigated the mechanical properties of concrete with fired ash gravel, including the use of steel fibers. Replacing 20-60% of coarse aggregates with fired ash gravel improved the workability of the mix but reduced the concrete's strength. With 40% replacement and the addition of fibers, the strength reached 42.6 MPa. The study [18] produced non-fired ash gravel from the Novosibirsk Thermal Power Plant, with characteristics of density 970 kg/m³ and strength 6.2 MPa, meeting European standards for lightweight concretes. Thus, compositions and technologies for lightweight aggregates from ash-slag waste have been developed, including both fired and non-fired gravel, using various binding agents.

The objective of the research is to develop compositions of lightweight structural concrete based on ash-slag waste.

The novelty of the work: for the first time, ash-slag aggregates based on the ash-slag from Almaty Thermal Power Plant-2 have been obtained using both firing and non-firing technologies. Based on these aggregates, lightweight concretes with an average density of 1250-1750 kg/m³ and compressive strengths after 14 days of curing of 10-14.5 MPa have been produced. Compositions of ash concrete without the use of aggregates have been developed, achieving compressive strengths after 28 days of curing of 12-18.2 MPa, corresponding to concrete grade M150 or classes B10 and B12.5.

Experimental part

Materials. For the experiments, the primary raw material component used is the fly ash from Almatinskaya TPP-2, which is produced from the combustion of coal sourced from the Ekibastuz coal basin. The actual specific activity of natural radionuclides in the fly ash ranges from 65 to 80 Bq/kg, allowing it to be used in housing construction without restrictions. The chemical composition of the fly ash from Almatinskaya TPP-2 is presented in Table 1.

Table 1 – Chemical composition of the fly ash from Almatinskaya TPP-2, wt.%

SiO_2	TiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Other impurities
65.0-65.9	1.1-1.18	21.9-22.7	4.55-7.71	2.2-2.37	0.48-0.92	0-0.84	0.48-0.52	0.96-1.19

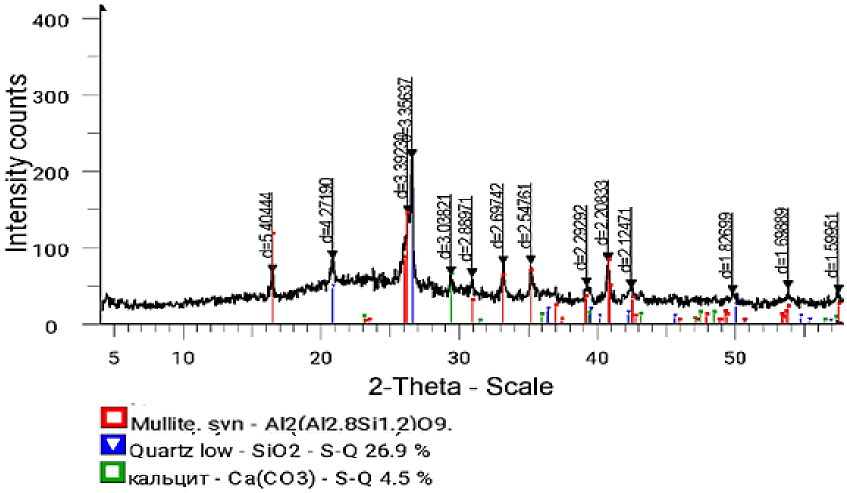

Figure 1 – X-ray Diffraction Pattern of Ash-Slag from Almaty TPP-2

X-ray phase analysis showed (fig. 1) that the mineralogical composition of the fly ash consists of mullite ($3Al_2O_3{\cdot}2SiO_2$) – 68.6%, quartz (SiO_2) – 26.9%, and calcite ($CaCO_3$) – 4.5%.

For the production of sintered fly ash aggregate, highly plastic bentonite clay was utilized. For the non-sintered fly ash aggregate, Portland cement CEM I 32.5 H (GOST 31108-2003) was used. To enhance the properties of fly ash concrete, the following additives were incorporated: calcium chloride as a hardening accelerator, Cemmix CemPlast as a superplasticizer, basalt fiber, asbestos fiber, and Sika ViskoCrete 20HE KZ as another superplasticizer.

Methods

To prepare the mixtures, the ash-slag and clay were dried in a drying oven at a temperature of 100-110 °C until a residual moisture content of 1-2% was achieved. When preparing clay-ash-slag mixtures, the dried clay was ground and sieved through a 0.63 mm mesh. To obtain filler granules, the ash-slag and clay were mixed in specified ratios, and then moistened with water to achieve a formable mass, from which granules with a diameter of 10-20 mm were produced using a laboratory granulator. After drying at 100-105 °C for 1-2 hours in the drying oven, the granules were fired in an SNOL 1.6/1300 muffle furnace. Following this, their density and strength were determined.

For preparing concrete mixtures, fired and unfired ash-slag fillers were used as coarse aggregates, and construction sand and ash-slag were used as fine aggregates. The curing of the ash-slag concrete samples was performed by keeping them in a humid environment for 7 and 28 days.

The chemical composition of the ash-slag was for clinker-based mixtures, the ash-slag was mixed with Portland cement in specified ratios, then moistened with water to form a workable mass, from which granules with a diameter of 10-20 mm were also produced. Additives were introduced into the mixture along with the mixing water. After shaping, the granules were cured in a humid environment for 14 days, after which their bulk density and compressive strength in a cylinder were measured.

For preparing concrete mixtures, both fired and unfired ash-slag fillers were used as coarse aggregates, while construction sand and ash-slag served as fine aggregates. The curing of the ash-slag concrete samples was performed by maintaining them in a humid environment for 7 and 28 days.

The chemical composition of the ash-slag was analyzed using a Rigaku NEX CG II Series spectrometer. X-ray diffraction (XRD) analysis of the ash-slag was conducted on a DRON-3 diffractometer with CuKα radiation and a β-filter. Diffraction conditions were set at U = 35 kV; I = 20 mA; scanning mode θ-2θ; and detector speed of 2 degrees/min. The interpretation of diffraction patterns was carried out using the ICDD data library.

The thermal conductivity of the ash-slag concrete was measured using an ITS-1 device. The physical and mechanical properties of lightweight aggregates were determined following the method described in [19], while the physical and mechanical properties of lightweight concrete were assessed according to the method in [20]. The thermal conductivity of lightweight concrete was measured with an ITP MG4 100 device.

Results and Discussion

1) Using the aforementioned methodology. Granules were produced from aluminosilicate mixtures, which were then subjected to firing at various temperatures. After cooling, their properties were determined. Table 2 presents the compositions of the batches and the properties of the aggregates based on ash-slag and bentonite clay after firing. As shown in Table 2, the compressive strength of the aggregates in the cylinder is sufficient for their application in the production of lightweight concrete. With an increase in the content of bentonite clay in the composition and the firing temperature, both the bulk density and strength of the aggregates significantly increase. Aggregates from compositions No. 1 and 2, containing 75-80% ash-slag and fired at temperatures of 1000-1100 °C, are optimal coarse aggregates for the production of lightweight concrete. Figure 2 shows samples of the aggregates.

2) Selection of unfired aggregate compositions.

For the formulation of mixtures to produce non-fired aggregates, fly ash and Portland cement CEM I 32.5 H were used. In the mixtures with Portland cement, the water-to-cement (W/C) ratio was set at 0.4 - 0.45. Calcium chloride (CaCl2) was added to the mixture with the mixing water.

Table 3 presents the composition and properties of ash-slag fillers obtained using non-fired technology.

As shown in Table 3, the fillers after curing for 14 days exhibit sufficient strength and bulk density within acceptable limits. An increase in the amount of cement in the filler compositions leads to enhanced strength and bulk density. The addition of CaCl2 contributes to increased compressive strength of the fillers in the cylinder. Figure 4 presents photographs of the fillers.

Table 2 – Compositions and properties of aggregate with bentonite clay

No.	Compositions	900 °C		1000 °C		1100 °C	
		ρ_{bulk}, kg/m^3	Compressive strength in cylinder, MPa	ρ_{bulk}, kg/m^3	Compressive strength in cylinder, MPa	ρ_{bulk}, kg/m^3	Compressive strength in cylinder, MPa
1	Ash-slag – 80% Bentonite clay – 20%	530	1.8	545	2.2	550	2.5
2	Ash-slag – 75% Bentonite clay – 25%	536	1.9	535	2.6	561	2.8
3	Ash-slag – 70% Bentonite clay – 30%	548	2.4	550	2.9	580	3.2
4	Ash-slag – 60% Bentonite clay – 40%	565	2.6	600	3.8	640	4.8

a) b)

a – before firing, b – after firing at 1000 °C

Figure 2 – Samples of ash-slag-based aggregates, composition No. 2

3) Properties of concrete with ash-slag aggregates.

Samples of lightweight concrete were produced using both non-fired and fired ash-slag aggregates. The concrete mixtures were formulated based on the composition calculation methodology outlined in the literature [21]. Two concrete compositions were calculated: Composition 1, which uses construction sand as the fine aggregate; and Composition 2, which replaces sand with ash-slag.

For the production of concrete samples with fired aggregates, we used the fired ash-slag aggregate from Composition No. 2 (Table 2). The concrete samples were formed into cubes measuring 100x100x100 mm on a laboratory vibrating table for 10-15 seconds. After forming, the samples were kept in metal molds for 10-12 hours, after which they were demolded. Further curing of the specimens was carried out at room temperature for 28 days in a humid environment.

Table 3 – Compositions and Properties of Lightweight Fillers Based on Ash-Slag and Portland Cement

No.	Compositions, %	ρ_{bulk}, kg/m³	Compressive strength in cylinder, MPa	Curing of the material
1	Ash-slag – 80 Cement – 20	644	1.79	At room temperature, in a humid environment, for 14 days.
2	Ash-slag – 75 Cement – 25	670	1.95	
3	Ash-slag – 70 Cement – 30	687	2.75	
4	Ash-slag – 80 Cement – 20 $CaCl_2$ – 3	637	2.73	
5	Ash-slag – 75 Cement – 25 $CaCl_2$ – 3	665	2.81	
6	Ash-slag – 70 Cement – 30 $CaCl_2$ – 3	690	2.98	

1 2 3

Figure 3 – Ash-slag aggregates with portland cement (sample numbering according to table 2)

a) b)

a – using quartz sand as the fine aggregate, b – using ash-slag sand as the fine aggregate

Figure 4 – Cube samples of lightweight concrete with fired ash-slag aggregate

After 28 days of curing, the average density and compressive strength of the concrete were determined. The average density of concrete with quartz sand was 1723 kg/m³, while the average density of concrete with ash-slag sand was 1210 kg/m³. The compressive strength of concrete with quartz sand was 17.9 MPa, and the compressive strength of concrete with ash-slag sand was 15.1 MPa. Measurements of thermal conductivity showed that the thermal conductivity coefficients of the produced concretes were 0.70 W/m·°C and 0.42 W/m·°C, respectively.

For the production of concrete samples, the non-fired ash-slag aggregate of Composition No. 5 (Table 3) was used. After 28 days of curing, the average density of the concrete with sand was 1750 kg/m³, while the average density of the concrete with ash-slag sand was 1250 kg/m³. The compressive strength of the concrete with quartz sand was 15.8 MPa, and the compressive strength of the concrete with ash-slag sand was 12.6 MPa. Thermal conductivity measurements indicated that the thermal conductivity coefficients of the produced concretes were 0.72 W/m·°C and 0.45 W/m·°C, respectively.

Thus, as the experimental data demonstrated, the compressive strength of ash-concrete samples using fired ash-slag aggregates is higher, while the average density is lower compared to the concrete samples produced with non-fired (clinker) aggregates.

4) Development of Ash Concrete Composition without Aggregates.

Table 4 presents the compositions and properties of ash-concrete samples with and without additives after curing for 7 and 28 days under normal conditions. The content of Portland cement in the concrete mixture ranges from 19.4% to 29.6%, the content of ash-slag ranges from 43.2% to 49.5%, and the remainder is water. As seen in Table 4, the amount of ash-slag in the concrete mixture exceeds the cement content by 1.5 to 2.5 times.

Analysis of the results presented in Table 4 shows that after 7 days of curing under natural conditions, the concrete samples without additives exhibit compressive strength in the range of 5.8 to 8.5 MPa. The increase in strength is attributed to the higher cement content in the concrete mixture.

The addition of an equal amount of CaCl2 at 3% (by weight of cement) to the concrete mixtures increases the compressive strength of the samples by 0.2 to 1.6 MPa after 7 days of curing [22]. The cube samples of ash-concrete without coarse aggregate are illustrated in Figure 5.

The addition of a plasticizer reduces the compressive strength of the ash-concrete samples by 0.1 to 1.2 MPa.

The incorporation of basalt fiber increases the compressive strength of the ash-concrete samples by 0.3 to 0.4 MPa.

Regardless of the type of additive, a correlation is observed between the strength of the ash-concrete and the cement content in its composition. It is noteworthy that the addition of CaCl2 has a significant effect on strength, contributing to an increase in the compressive strength of the ash-concrete samples. This is clearly illustrated in Figure 6, which displays the strength results of concrete samples with and without additives.

The compressive strength of the ash-concrete samples after 28 days of curing (Table 4) without additives ranges from 13.6 to 16.3 MPa, which is 2 to 2.3 times higher than the 7-day strength. This corresponds to a concrete grade of M150 or a concrete class of B10-B12.5 [20]. Ash-concrete samples with the addition of CaCl2 after 28 days of curing exhibit compressive strength that is 1.8 to 2 times higher than the 7-day strength, ranging from 12 to 18.2 MPa. Among these, the samples with compositions No. 6, No. 7, and No. 8 correspond to the concrete grade M150, i.e., concrete classes B10 and B12.5.

Ash-concrete samples with a plasticizer generally demonstrate lower strength compared to those without additives. However, the strength of compositions No. 11 and No. 12 qualifies them for class B10 concrete.

Ash-concrete samples with basalt fiber additives also show lower compressive strength after 28 days of curing compared to the samples without additives. This can be attributed to the smooth surface of the fiber and its low adhesion to the ash. In this series, the strength of compositions No. 14, No. 15, and No. 16 qualifies them for concrete class B10.

Table 4 – Compositions and Properties of Ash-Concrete Samples

No	Weight composition of ash concrete			Additives	Compressive strength after 7 days, MPa	Compressive strength after 28 days, MPa	Average density, kg/m³
	Cement	Ash	W/C				
1	1	2.55	1.6	-	5.8	13.6	1557.5
2	1	1.91	1.27	-	6.3	15.7	1568.5
3	1	1.67	1.08	-	6.4	16.2	1574.3
4	1	1.46	0.92	-	8.5	16.3	1638.4
5	1	2.55	1.6	3 % $CaCl_2$	6.0	12.0	1574.3
6	1	1.91	1.27	3% $CaCl_2$	7.8	15.2	1489.7
7	1	1.67	1.08	3 % $CaCl_2$	9.5	17.5	1586.0
8	1	1.46	0.92	3 % $CaCl_2$	10.1	18.2	1626.8
9	1	2.55	1.6	Plasticizer	4.6	10.0	1492.7
10	1	1.91	1.27	-//-	4.9	12.4	1518.9
11	1	1.67	1.08	-//-	6.6	13.0	1548.0
12	1	1.46	0.92	-//-	8.4	15.4	1495.6
13	1	2.55	1.6	5 g Fiber	6.1	12.1	1561.0
14	1	1.91	1.27	5 -//-	6.8	14.5	1573.0
15	1	1.67	1.08	5 -//-	6.9	14.8	1581.2
16	1	1.46	0.92	5 -//-	8.8	15.0	1588.3

Figure 5 - Cube samples of ash-concrete without coarse aggregate: composition No 7 with 3% $CaCl_2$ additive (table 4)

Figure 7 illustrates the graphical relationship between the average density of fly ash concrete samples and their composition. The average density varies from 1490 to 1638 kg/m³ and generally increases with the rising amount of cement in the mixture.

According to [20], the produced fly ash concrete samples are classified within the medium-strength category (compressive strength class B < B40), specifically class B5. Based on their average density, these samples are categorized as lightweight structural-thermal insulating and structural concrete (density grades ranging from D800 to D1800).

Thus, the conducted studies demonstrate the feasibility of producing fly ash concrete samples without the incorporation of traditional construction sand in the mixture.

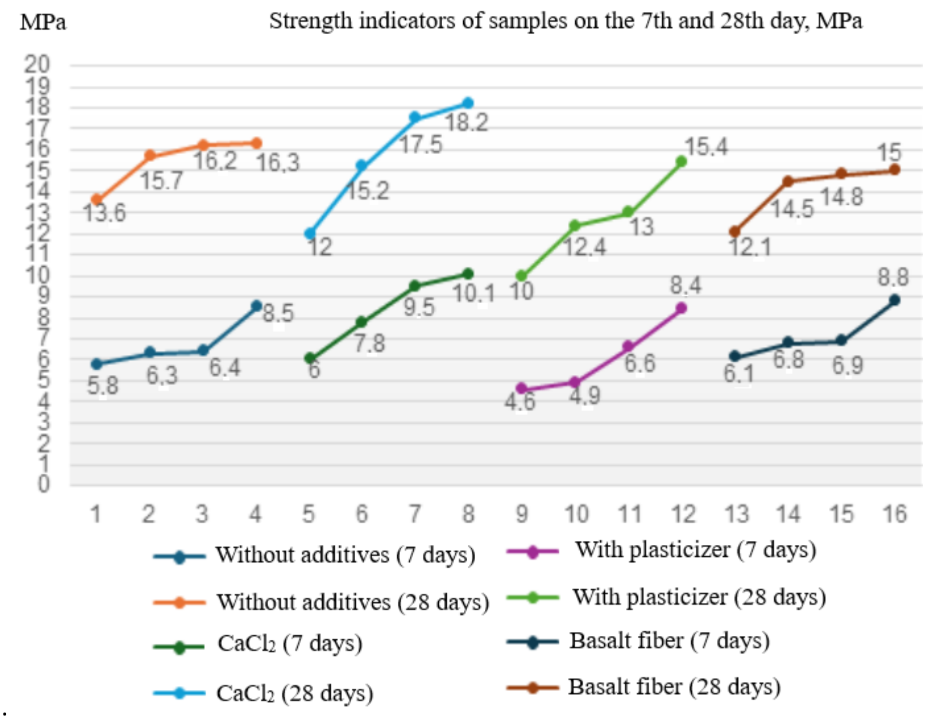

Figure 6 – Changes in the compressive strength of fly ash concrete samples depending on the composition at 7 and 28 days of curing

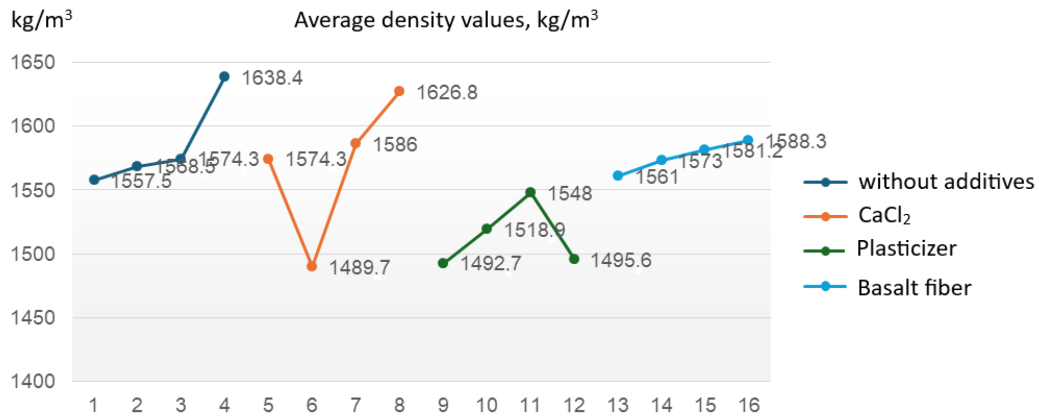

Figure 7 – Changes in the density of fly ash concrete samples depending on the composition at 28 days of curing

A rational selection of fly ash concrete mixture compositions, where the ash content is 1.5 to 2.5 times higher than the cement content, enabled the investigation of the impact of various additives on the properties of the samples based on a limited number of experiments.

The compressive strengths of the concrete samples were determined after 7 and 28 days of curing. It was found that the strength of all fly ash concrete samples after 28 days of curing is 1.5 to 2.3 times higher than their strength at 7 days. A dependency of fly ash concrete strength on the cement content in the mixture was observed, regardless of the type of additive used.

It was established that the fly ash concrete samples without additives, after 28 days of natural curing, correspond to the concrete grade M150 or strength class B10-B12.5.

Fly ash concrete samples containing a plasticizer and basalt fiber generally exhibit lower strength values compared to those without additives. However, samples from these series that contain an increased amount of cement achieve strength values that qualify them as B10 concrete.

Fly ash concrete samples with the addition of CaCl2 after 7 days of curing show a compressive strength that is 0.2 to 1.6 MPa higher than the samples without additives. This indicates that CaCl2 enhances the strength of the concrete in the early stages of curing. After 28 days of curing, the fly ash concrete samples with CaCl2 exhibit a compressive strength of 12 to 18.2 MPa, corresponding to a concrete grade of M150 or strength classes B10 and B12.5.

The most optimal fly ash concrete mixes for manufacturing large products are recommended to be compositions No. 2 and No. 3 without additives, and No. 6 and No. 7 with the addition of CaCl2. The fly ash content in these mixes is 44-45%. Measurements of the thermal conductivity of compositions No. 6 and No. 7 showed thermal conductivity coefficients of 0.612 and 0.618 W/m·°C, respectively.

Overall, the fly ash concrete samples exhibit compressive strengths of 13 to 18.2 MPa, corresponding to a strength class of B10-B12. The average density of the products ranges from 1500 to 1600 kg/m³, which, according to GOST standards, classifies them as structural-thermal insulation concretes.

Conclusions

1. For the first time, sintered ash-slag aggregates have been produced from ash slag of the Almaty TPP-2 and bentonite clay, achieving a bulk density of 530-640 kg/m³ and compressive strength of 1.8-4.8 MPa. Lightweight concretes with densities of 1723 kg/m³ and 1210 kg/m³ were manufactured, exhibiting strengths of 17.9 MPa and 15.1 MPa, respectively. The thermal conductivity of these concretes is 0.70 W/m·°C and 0.42 W/m·°C.

2. Using Portland cement, non-sintered ash-slag aggregates have been obtained with a bulk density of 644-690 kg/m³ and compressive strength of 1.79-2.98 MPa. Lightweight concretes with densities of 1750 kg/m³ and 1215 kg/m³ have strengths of 15.8 MPa and 12.6 MPa, with thermal conductivities of 0.75 W/m·°C and 0.43 W/m·°C, respectively.

3. The density and strength of the concrete meet the requirements of GOST 25820-2014.

4. Mixture compositions of ash concrete have been developed without traditional sand and with increased ash-slag content, allowing for the study of the effects of additives on the properties of the samples.

5. The compressive strength of the ash concrete samples after 28 days of curing is 1.5 to 2.3 times greater than that after 7 days. The strength is dependent on the cement content in the mixture.

6. Ash concretes without additives after 28 days correspond to grade M150 or strength class B10-B12.5. Samples with additives exhibit lower strength; however, those with increased cement content can be classified as B10.

7. Ash concretes with CaCl2 show a compressive strength that is 0.2 to 1.6 MPa higher after 7 days compared to those without additives. After 28 days, the strength ranges from 12 to 18.2 MPa, corresponding to grade M150 or strength classes B10 and B12.5.

8. The optimal compositions for large product manufacturing are No. 6 and No. 7 with CaCl2 (with an ash-slag content of 44-45%). The thermal conductivity is measured at 0.612-0.618 W/m·°C.

9. The ash concrete samples exhibit average strength (class B5) and are classified by density as lightweight structural-thermal insulating and structural concretes (D800-D1800).

Conflict of interest. On behalf of all the authors, the correspondent author declares that there is no conflict of interest.

***CRediT author statement*. R. Nurlybayev., M. Zhuginissov and E.Kuldeyev:** Conceptualization; **Zhuginissov., A.Iskakov and Y.Orynbekov:** Methodology; **Y.Khamza., Y.Orynbekov and A. Iskakov:** Software; **R.Nurlybayev., M.Zhuginissov and Y.Orynbekov:** Formal analysis; **M.Zhuginissov and Y.Orynbekov:** Writing—original draft preparation; **E.Kuldeyev and R.Nurlybayev:** Visualization, Project administration, Funding acquisition. All authors have read and agreed to the published version of the manuscript.

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ЖЭС күлін пайдалана отырып алынған жеңіл конструкциялық жылу оқшаулағыш бетон

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ТҮЙІНДЕМЕ
Мақалада Алматы ЖЭС-2 күл-қож қалдықтары негізінде жеңіл конструкциялық бетондарды алу нәтижелері ұсынылған. Күл-қож толтырғыштары күйдіреін және күйдірмейтін (клинкерлі) технологиялар бойынша дайындалды. Күйдіру әдісімен бентонитті саз негізіндегі толтырғыштар 530-640 кг/м^3 көлемдік тығыздығымен және 1,8–4,8 МПа беріктігімен сипатталды. Күйдірілмеген толтырғыштардың портланд цементтегі тығыздығы 644-690 кг/м^3 және беріктігі 1,79–2,98 МПа болады, ал сұйық шыныдағы толтырғыштың тығыздығы 562-642 кг/м^3 және беріктігі 1,93 — 3,8 МПа болды. Алынған толтырғыштардан МЕМСТ 25820-2014 талаптарына сәйкес келетін тығыздығы 1210-1750 кг/м^3 және беріктігі 100-152 кг/м^3 жеңіл бетондар жасалды. Ірі толтырғышсыз күл негізіндегі бетонның қасиеттеріне $CaCl_2$-дың әсері, суперпластификатор және базальт талшықтары қоспаларының әсері зерттелді. Бетондардың беріктігі 28 тәуліктен кейін 7 тәулік пен салыстырғанда 1,5-2,3 жоғары болып, оған $CaCl_2$ үлкен әсер етті. Тығыздығы 1500-1600 кг/м^3, В10–В12 класты күл бетондары алынып, МЕМСТ бойынша оларды құрылымдық-жылу оқшаулағыш бетондарға жатқызуға мүмкіндік береді. Зерттеудің мақсаты күл-қож қалдықтары негізінде жеңіл құрылымдық бетондардың құрамын алу. Жұмыстың жаңалығы: Алғаш рет Алматы ЖЭС-2 күл-қожының негізінде күйдіру және күйдірілмеген технологияларды пайдалана отырып күл-қож толтырғыштары алынды.

Түйін сөздер: күл-қож, күлді бетон, толтырғыш, бентонит сазы, күйдіру, қатаю, тығыздық, беріктік.

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Легкий конструкционно-теплоизоляционный бетон с применением золы ТЭЦ

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АННОТАЦИЯ
В статье представлены результаты разработки легких конструкционных бетонов на основе золошлаковых отходов Алматинской ТЭЦ-2. Золошлаковые заполнители изготавливались по обжиговой и безобжиговой (клинкерной) технологиям. Обжиговые заполнители, полученные с использованием бентонитовой глины, характеризовались насыпной плотностью 530–640 кг/м^3 и прочностью 1,8–4,8 МПа. Безобжиговые заполнители на портландцементе имели плотность 644–690 кг/м^3 и прочность 1,79–2,98 МПа, а на жидком

Поступила: 17 *ноября 2024* Рецензирование: *27 ноября 2024* Принята в печать: *13 декабря 2024*	стекле — 562–642 кг/м³ и 1,93–3,8 МПа. Из полученных заполнителей изготовлены легкие бетоны с плотностью 1210–1750 кг/м³ и прочностью 100–152 кг/м³, соответствующие требованиям ГОСТ 25820-2014. В составах без крупного заполнителя изучено влияние добавок $CaCl_2$, суперпластификатора и базальтовой фибры на свойства золобетона. Прочность бетонов через 28 суток превышала 7-суточную в 1,5–2,3 раза, с наибольшим эффектом от $CaCl_2$. Получены золобетоны класса В10–В12 с плотностью 1500–1600 кг/м³, по ГОСТу позволяет отнести их к конструкционно-теплоизоляционным бетонам. Целью исследования является разработка составов легких конструкционных бетонов на основе золошлаковых отходов. Новизна работы: Впервые на основе золошлака Алматинской ТЭЦ-2 получены золошлаковые заполнители по обжиговой и безобжиговой технологиям.
	Ключевые слова: золошлак, золобетон, заполнитель, бентонитовая глина, обжиг, твердение, плотность, прочность.
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References

[1] Sirotiuk VV, Troian TP. Vliianie uglistykh ostatkov na kachestvo zoloshlakov, primeniaemykh dlia stroitelnykh tekhnologii [The influence of carbon residues on the quality of ash-slag materials used in construction technologies]. Herald of SibADI. Omsk. 2017; 6(58):119-125. (in Russ.). https://doi.org/10.26518/2071-7296-2017-6(58)

[2] Narinder Singh, Jehangeer Raza, Francesco Colangelo and Ilenia Farina. Advancements in Lightweight Artificial Aggregates: Typologies, Compositions, Applications, and Prospects for the Future. Sustainability. 2024; 16(21):9329. https://doi.org/10.3390/su16219329

[3] Cheng Liu,Xinyan Wang,Yujiao Li,Qiuyi Li andGongbing Yue. Evaluation on Preparation and Performance of a Low-Carbon Alkali-Activated Recycled Concrete under Different Cementitious Material Systems. Materials. 2024; 17(19):4869. https://doi.org/10.3390/ma17194869

[4] Akelamjiang Maimait, Yaqiang Wang, Jianjun Cheng, Yanfu Duan andZhouyang Pan. Research on the Configuration of Multi-Component Solid Waste Cementitious Materials and the Strength Characteristics of Consolidated Aeolian Sand. Buildings. 2024; 14(10):3059. https://doi.org/10.3390/buildings14103059

[5] Fei Wang, Huihui Du, Zhong Zheng, Dong Xu, Ying Wang, Ning Li, Wen Ni and Chao Ren. The Impact of Fly Ash on the Properties of Cementitious Materials Based on Slag-Steel Slag-Gypsum Solid Waste. Materials. 2024; 17(19):4696. https://doi.org/10.3390/ma17194696

[6] Ke Wu, Zhenhua Liu, Cao Wang, Tao Yang, Zhongyu Dou and Jiaxiang Xu. Study of Semi-Adiabatic Temperature Rise Test of Mineral Admixture Concrete. Buildings. 2024; 14(9):2941. https://doi.org/10.3390/buildings14092941

[7] Pat. № 2232141 RU. Sposob polucheniia legkogo zapolnitelia [Method for producing lightweight aggregate]. Maksimov B.A., Petrov V.P., Korenkova S.F. Opubl. 10.06.2004. https://www.fips.ru/iiss/document.xhtml?faces-redirect=true&id=fe463a4a1ba6480fbbaa40b56660b3e1

[8] Kayali O. Fly ash lightweight aggregates in high performance concrete. Construction and Building Materials. 2008; 22(12):2393-2399. https://doi.org/10.1016/j.conbuildmat.2007.09.001

[9] González-Corrochano B, Alonso-Azcárate J, & Rodas M. Characterization of lightweight aggregates manufactured from washing aggregate sludge and fly ash. Resources, Conservation and Recycling. 2009; 53(10):571-581. https://doi.org/10.1016/j.resconrec.2009.04.008

[10] David Torréns-Martín, Lucía J Fernández-Carrasco and María Teresa Blanco-Varela. Up to 100% Replacement of Natural Materials from Residues: Recycling Blast Furnace Slag and Fly Ash as Self-Leveling Cementitious Building Materials. Materials. 2023; 16(9):3350. https://doi.org/10.3390/ma16093350

[11] Andrés Caño, José Antonio Suárez-Navarro, Francisca Puertas, Ana Fernández-Jiménez and María del Mar Alonso. New Approach to Determine the Activity Concentration Index in Cements, Fly Ashes, and Slags on the Basis of Their Chemical Composition. Materials. 2023; 16(7):2677. https://doi.org/10.3390/ma16072677

[12] Likang Bai, Zhenjia Yang, Yang Wu, Mohadeseh Anbarlouie and Zhu Pan. Stabilization of Aeolian Sand for Pavement Subbase Applications Using Alkali-Activated Fly Ash and Slag. Minerals. 2023; 13(3):453. https://doi.org/10.3390/min13030453

[13] Tianxiang Chen, Ning Yuan, Shanhu Wang, Xinfei Hao, Xinling Zhang, Dongmin Wang and Xuan Yang. The Effect of Bottom Ash Ball-Milling Time on Properties of Controlled Low-Strength Material Using Multi-Component Coal-Based Solid Wastes. Sustainability. 2022; 14(16):9949. https://doi.org/10.3390/su14169949

[14] Kockal NU, Ozturan T. Microstructural and mineralogical characterization of artificially produced pellets for civil engineering applications. Journal of Materials in Civil Engineering. 2017; 29(2). https://doi.org/10.1061/(ASCE)MT.1943-5533.0001739

[15] Cerny V, Kocianova M, Drochytka R. Possibilities of Lightweight High Strength Concrete Production from Sintered Fly Ash Aggregate. Procedia Engineering. 2017; 195:9-16. https://doi.org/10.1016/j.proeng.2017.04.517

[16] Dash S, Kar B, Mukherjee PS. Pervious concrete using fly ash aggregate as coarse aggregate-an experimental study. AIP Conference Proceedings. 2018, 1953. https://doi.org/10.1063/1.5032808

[17] Babu BR, Thenmozhi R. An investigation of the mechanical properties of Sintered Fly Ash Lightweight Aggregate Concrete (SFLWAC) with steel fibers. Archives of Civil Engineering. 2018; 64(1):73-85. https://doi.org/10.2478/ace-2018-0005

[18] Sérgio Roberto Da Silva andJairo José de Oliveira Andrade. A Review on the Effect of Mechanical Properties and Durability of Concrete with Construction and Demolition Waste (CDW) and Fly Ash in the Production of New Cement Concrete. Sustainability. 2022; 14(11):6740. https://doi.org/10.3390/su14116740

[19] GOST 9758-2012. Zapolniteli poristye neorganicheskie dlia stroitelnykh rabot [Inorganic porous aggregates for construction works]. Test Methods. Moscow: Interstate Standard. 2014. (in Russ.). https://meganorm.ru/Data/541/54152.pdf

[20] GOST 25820-2014 Betony legkie. Tekhnicheskie usloviia [Lightweight concrete]. Technical Specifications. Moscow: Standartinform. 2019. (in Russ.). https://meganorm.ru/Data2/1/4293767/4293767129.pdf

[21] Zhiwei Qu, Zihao Liu, Ruizhe Si and Yingda Zhang. Effect of Various Fly Ash and Ground Granulated Blast Furnace Slag Content on Concrete Properties: Experiments and Modelling. Materials. 2022; 15(9):3016. https://doi.org/10.3390/ma15093016

[22] Ruize Zhao, Chenglin Shi, Ruixin Zhang, Wensheng Wang, Huirong Zhu and Jing Luo. Study on the Freeze-Thaw Resistance of Concrete Pavements in Seasonally Frozen Regions. Materials. 2024; 17(8):1902. https://doi.org/10.3390/ma17081902