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Zhakypova, Gulnur
Institute of Engineering and Technology, Korkyt Ata Kyzylorda University

Uderbayev, Saken
Department of Architecture and Construction, Korkyt Ata Kyzylorda University

Saktaganova, Nargul
Department of Architecture and Construction, Korkyt Ata Kyzylorda University

Abyieva, Guldana
Department of Engineering Systems and Networks, International Educational Corporation

他

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Properties of Fine-Grained Concrete Using Ash of Kazakhstan

Gulnur Zhakypova[1], Saken Uderbayev[2,*], Nargul Saktaganova[2], Guldana Abyieva[3], Aigul Budikova[2], Akmaral Zhapakhova[2]

[1]Institute of Engineering and Technology, Korkyt Ata Kyzylorda University, Republic of Kazakhstan

[2]Department of Architecture and Construction, Korkyt Ata Kyzylorda University, Republic of Kazakhstan

[3]Department of Engineering Systems and Networks, International Educational Corporation, Republic of Kazakhstan

*Author to whom correspondence should be addressed:
E-mail: g.zhakypova8@gmail.com

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Abstract: The aim of the work is a study of the physical and mechanical properties of fine-grained concrete using ash of Kazakhstan (namely: the influence of dispersion of hydro-removal ash and liquid glass additives on the properties of fine-grained concrete). This study aims to address the issue of improving the environmental impact, which ensures the quality of concrete by saving cement. It was established that ash in concrete contributed to the formation of a denser structure of the intergranular space of aggregates and a less defective contact zone of aggregates with cement stone. The analysis of the obtained results showed that ash-cement concretes hardened slowly under natural conditions. In the period of 7-14 days of hardening, as a rule, the strength of samples of fine-grained concrete with the addition of hydroremoval ash is lower than the strength of reference samples without ash. The increase in the strength of the samples in the period of 60 days was 6.6...7.0%, and in the period of 90 days - 15.0...15.5% compared to the strength of 28 days. The experiments on ash absorption of CaO hydro removal from lime mortar were carried out. The degree of hydration in the ash-cement stone of the studied composition of the developed binder was determined. Research has shown that with a decrease in the concentration of calcium hydroxide in the liquid phase, the activity of the ash increases. This can be explained by the high content of the glass phase. The balance of hydrate neoplasms in the ash-cement binder was experimentally determined. The research results indicate the possibility of using ash in the production of crushed stone concrete as part of the following building materials: dense wall blocks, curbs, paving slabs, for pouring floors, for sound insulation, as a brick mortar.

Keywords: industrial waste disposal; coals with high ash content; pozzolanic activity; glass phase; ash-cement concrete

1. Introduction

One of the main factors determining the urgency of developing and implementing energy- and resource-saving technologies for various types of concrete is the general growth in cement consumption and, accordingly, the increase in the amount of carbon dioxide emissions into the atmosphere during its production. In addition, the increase in energy and resource costs for the production of concrete leads to an increase in its cost, which is an additional economic burden on the construction industry.

In Kazakhstan and other countries of Central Asia, where significant development of the construction industry is observed, there is great potential for the application of energy- and resource-saving technologies in concrete production. In particular, the possibility of using Kazakhstan ash to produce fine-grained concrete can help save cement and reduce CO_2 emissions during concrete production. Also, the use of new binding materials, additives and smart technologies can reduce the consumption of energy and resources for production and ensure the creation of a more environmentally friendly and efficient building material. Thus, one of the topical issues is the development and implementation of energy and resource-saving technologies for various types of concrete both in Kazakhstan and in the countries of Central Asia. In this regard, researchers, assessing the natural resource potential and the mineral resource database of countries, determine the need to create an integrated approach to the joint development and use of resources available in different countries for cost-effective and environmentally safe environmental management and resource management.

The astringency of Kazakhstan ash is an important characteristic, as it allows it to become an effective aggregate for the production of fine-grained concrete. As the astringency of ash increases, the filling of the intergranular space with aggregates improves, which provides a denser concrete structure. Thus, the use of Kazakhstani fly ash can help reduce the amount of cement needed to produce concrete, thereby saving resources and reducing the negative impact on the environment.

The main directions for the development of the national economy in all countries and the development of integrated approaches to the conservation of mineral raw materials and natural were developed by the authors in the following resources work[1].

The use of hydraulic ash with a rational grain composition as an additive in the production of concrete, which is the most urgent task of saving cement and ecology (annual discharges of ash and slag from coal combustion increase the total amount of stored waste, cause serious harm to the environment, and put it out of circulation large tracts of land).

In order to conserve natural resources, some measures are currently taken to create various composite materials based on various wastes. For example: the work is underway to analyze the methodological features of assessing the strength and deformation properties of composites based on asphalt granules and to study the processes of structuring. These new materials require a study of the characteristics of their properties under the influence of temperature and time to create objective technical requirements for their physical and mechanical characteristics that provide the required strength and durability. The proposed methodological principles of this project are based on establishing the optimum ratio of elastic and strong bonds in the material under study, which take into account the properties of its constituent components and the amount of cement. The use of this approach makes it possible to evaluate the prospects for achieving the maximum durability of composites, the feasibility of introducing various converting components, and the optimal limit for the consumption of an organic binder[2].

The aggravation of environmental problems forces to focus on the possibility of recycling technogenic raw materials and involving them in the technological process, and due to the accumulation of a large amount of technogenic waste from industrial complexes and a decrease in the level of target components in the feedstock, the issue of their integrated use is actual in the modern world[3].

They are usually based on genetic characteristics, i.e., formation conditions, composition (mineral, less often chemical), dispersion. According to the classification (Figure 1) waste can be divided into technogenic; pyrogenic; chemogenic; biogenic. At the same time, pyrogenic and mechanogenic ones are of the greatest interest for the construction industry, due to their composition and properties.

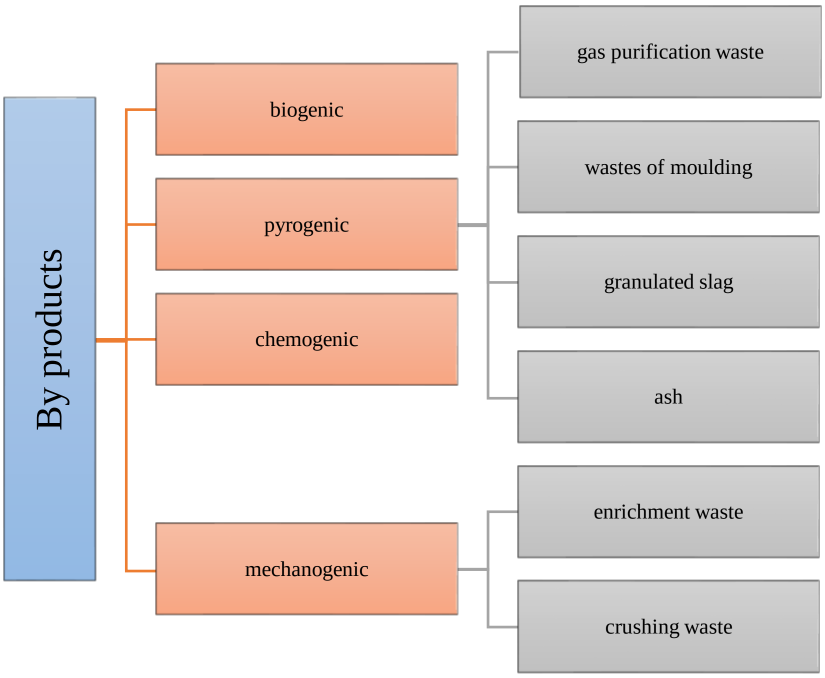

Fig. 1: Classification of man-caused materials

Among technogenic raw materials of pyrogenic origin, one of the first places in terms of formation volume is occupied by ash and slag from the combustion of solid fuels. This is due to the fact that the main source for generating electricity in Kazakhstan are fossil fuels (anthracite, brown and hard coal, oil shale, peat)[4].

At high-temperature combustion of coal in the furnace with liquid slag removal, granulated slag was obtained, and experience showed the prospects of this method of combustion, as 80% of ash was captured within the furnace chamber. When, in turn, in furnaces with solid ash removal, this indicator was 20%. Today, the Danish and German building material industry uses close to 100% ash and slag waste. The second method is the combustion of coal in furnaces with a circulating fluidizer bed. The main advantage of this method is compactness and the possibility to burn coal of any ash content. In Europe, the USA, China, and India the second method is used.

Thus, the study of the physical and mechanical properties of fine-grained concrete using Kazakhstan ash is relevant, as the problem of improving the impact on the environment and reducing the use of cement in construction is raised. The use of ash in the production of building materials can be economically beneficial and favorable for the environment, which makes this research relevant for solving this problem. This work investigates the influence of the dispersion of fly ash and liquid glass additives on the properties of fine-grained concrete. Its importance lies in solving the problem of improving the quality of concrete and reducing the impact on the environment by saving cement. And the research results indicate the possibility of using ash in the production of various building materials, which can be useful for the construction of environmentally friendly and wear-resistant buildings and will contribute to sustainable development.

Thus, the aim of the work is a study of the influence of the dispersion of hydro-removal ash and liquid glass additives on the properties of fine-grained concrete.

Based on the goal, the following research tasks were set:

1. To investigate the influence of the dispersion of hydroremoval ash and liquid glass additives on the physical and mechanical properties of fine-grained concrete.
2. To determine how ash affects the structure of the intergranular space of aggregates and the area of contact between aggregates and cement stone.
3. To investigate the hardening rates of fine-grained concrete with the addition of ash and compare them with reference samples without ash.
4. To study the increase in strength of samples of fine-grained concrete with the addition of ash for 60 and 90 days compared to the strength at 28 days.
5. Conduct experiments on ash absorption of hydroremoval of CaO from a lime solution and determine the degree of hydration in the ash slag of the studied composition of the binder.
6. Investigate the influence of the concentration of calcium hydroxide in the liquid phase on the activity of ash and establish the relationship between them.
7. Determine the possibility of using ash in the production of construction materials, in particular crushed stone, for various purposes.

2. Theoretical overview

About 40% of the total electricity in the world is produced at coal-fired thermal power plants, of which in the USA, Germany and some other countries – about 70%. It is assumed that the growth in electricity production would occur due to the even more decisive development of coal energy in China, the United States and many other countries at least until 2030[5-7].

The cement industry is one of the rapidly developing areas. Today, the attention is focused on the process of carbon dioxide release from the composition of cement. The cement slurry tends to be high viscosity, low flow ability, solubility and clogging in the cementing technique. The cement slurry is made using ultra-fine cement (SC) in the research. The part of the very fine crushed ash is used instead of cement, because limestone wastes $mSiO_2$ * nH_2O is obtained from them, which are mainly commingled with a mixture of an aqueous reducing agent of polycarboxylic ceramics. As the viscosity decreases, a number of physical characteristics change. For example, fluidity increases and the viscosity process decreases[8-10]. The mixtures were made based on the results of a one-factor test to determine the optimal ratio of the cement mixture mixed with mortars with different materials. The Taguchi correlation analysis method was used in the research. A solution with the optimal ratio of the components of the mixture was used, and its stability was analyzed. The research results showed that the cement slurry with the optimal ratio of SH, SC, PR and UFA components were of good fluidity and solubility, they had stable development characteristics and could be used in practical projects[10-12].

The technological processes must ensure the return of raw materials by recycling industrial waste in order to establish a balance in the environment. Currently, ash waste is stored in special alluvial hydraulic structures – ash dumps, the area of which is about 20 thousand hectares, and the volumes depend on the ash content of coal. Brown coal waste is distinguished by a high content of calcium oxide (up to 30%), iron oxide (up to 15%) and a low ash content of about 7...10%. However, coal with a high ash content have also been used as fuel in recent decades[13,14].

The high ash content of coal causes a big environmental problem. In addition, the ashes of Ekibastuz coals are practically impossible to use in firing building materials (porous aggregates, clay and ash bricks), since they are low-iron (Fe2O3 about 7%, A12O3 about 30%) and refractory[15,16].

The concentration of calcium hydroxide in the liquid phase can affect the activity of the ash. Reducing the concentration of calcium hydroxide increases the activity of ash. This can be explained by the fact that the ash composition contains a large amount of glass phase, which can be more active than cement powder. Therefore, reducing the concentration of calcium hydroxide can increase the activity of ash, which can contribute to faster hardening of ash-cement concrete. Ash coals do not have the ability to directly interact with water. The composition of the studied ash is given in Table 1. At the same time, ashes in the composition of mixed binders (ash-cement) participate in hardening and exhibit pozzolanic activity during hardening, i.e., the ability at ordinary temperatures to bind calcium hydroxide with the formation of insoluble compounds.

Table 1. The average chemical composition of ash, hydraulic removal

P.p.p, % mass	Oxide, % mass						
	SiO_2	Al_2O_3+TiO_2	Fe_2O_3	CaO	MgO	Na_2O	SO_2
7.33	48.53	23.92	5.94	9	1.9	0.18	0.52

Clay firing products have pozzolanic activity in the composition of the ashes: amorphous clay substance of the metakaolins type, amorphous SiO_2, Al2O3, Fe_2O_3 and aluminosilicate glass. Their reactivity in relation to calcium hydroxide is different. Having a large specific surface, metakaolins actively reacts with $Ca(OH)_2$ at ordinary temperatures to form calcium hydrosilicates and hydrogelenite. The activity of amorphous SiO_2 and Al_2O_3 formed at higher temperatures is noticeably lower, which is explained by a sharp decrease in the specific surface area due to sintering and crystallization of kaolinite decomposition products (mullite, cristobalite, etc.)[1,2].

High-temperature sintering and melting of clay minerals reduces their specific surface and, accordingly, activity, therefore, the aluminosilicate glass phase of ash is inactive at ordinary temperatures. Some crystalline components of ash-quartz, feldspar, and calcium aluminosilicates exhibit activity at elevated temperatures.

The nature of the interaction of the components of the ashes with water and aqueous solutions of $Ca(OH)_2$ during the hardening of binders depends, firstly, on the ratio of the solubility of the reacting substances. With a large difference in solubility, the interaction and isolation of neoplasms are carried out on the surface of the hardly soluble component. The comparative solubility of clay minerals and products of their firing (feldspars or micas) increases sharply with an increase in its alkalinity [16-18].

The surfaces of the ash particles are hydrated, the hydrated glass phase actively absorbs calcium ions from the liquid phase. The hardening products of mixed gold-cement binders are hydrosilicates and calcium hydrogarnets. The evaluated results show that ash contributes to the formation of a denser structure of the intergranular space of aggregates and a less defective zone of contact of aggregates with cement stone. However, the questions about how the dispersion of ash from hydroremoval and liquid glass additives affect the properties of fine-grained concrete, and how it is possible to reduce the hardening time of ash-cement concrete in natural conditions, have not yet been fully resolved. Also, some aspects of ash absorption of hydroremoval of CaO from lime solution and corresponding hydration processes in ash slag of the investigated composition of the developed binder have not been studied. Questions also concern the possibility of using ash in the production of various building materials, such as tiles, blocks, curbs, etc.

3. Materials and methods

The object of the study is the industrial waste of enterprises, namely ash and slag waste, and their effect on the properties of fine-grained concrete. The objects of the study were ash and slag waste from the Balkhash TPS in the southern region of Kazakhstan. During its operation, cheap Ekibastuz coal is used, which is characterized by a high ash content of up to 60%.

During the research, the following materials were used: hydro-removal ash (% mass: SiO_2 – 48.53, Al_2O_3 +TiO_2 – 23.92, Fe_2O_3 – 5.94, CaO – 9, MgO – 1.9, Na_2 O – 0.18), cement stone (portland cement M 500), sand Mcr = 1.8, a mixture of liquid glass, water. Hydro removal ash, with a highly dispersed grain composition of 0.9-27 microns, was obtained by mechanical grinding. Ash pre-treatment by grinding and magnetic separation is carried out to bring it to stable characteristics in terms of granulometric, chemical, and phase compositions. Processing transfers ash from the category of waste to high-quality raw materials, which increases its reactivity and leads to the destruction of large CaO particles, which react with water more slowly than the main mass (leads to an uneven change in the volume of ash concrete and eventually cracking). The optimal content of hydro-removal ash (10%), with a dispersion of 200-250 m^2/kg, and the addition of liquid glass (CTejam) in a percentage of 3% was established.

Closest to the technical result and taken as a prototype is a method of preparing ash concrete, obtained by mixing Portland cement, ash, sand, crushed stone, and water. All components of the concrete mixture are simultaneously introduced into the concrete mixer and mixed until homogeneous[19]. For the experiment, samples were molded with a size of 7x7x7 cm, and the composition: C: T = 1:3, ash – 10% by weight of cement, the addition of liquid glass – 3% by weight of cement, water – the rest.

The methodological basis of the study is based on the use of theoretical and empirical methods, which are based on comparison, generalization, the method of a systematic approach, and mathematical modeling, processing the results of the experiment. Experimental studies were carried out on laboratory samples using modern methods of analysis: electron microscopic, X-ray phase, laser granulometry, and chemical analysis.

During the tests, an X-ray diffraction pattern of the initial acidic ash from hydraulic removal was performed, which confirmed the presence of quartz, mullite, and calcite. Hematite and maghemite magnetite are also present. To control the rheological properties of the ash-concrete mixture of the obtained concretes, standard methods were applied. Qualitative and quantitative chemical analysis of the samples was carried out using X-ray fluorescence analysis of hydro removal ash.

An ARL OPTIM X scanning spectrometer (Thermo Electron Corporation) was used in the study. ARL OPTIM X WD-XRF spectrometer is a crystal-diffraction X-ray spectrometer with wavelength diffraction. This instrument allows qualitative and quantitative determination of elements from A1 to U in solid (powder) and liquid samples.

Sample preparation of the catalyst for qualitative and quantitative analysis by the XRF method was carried out. It includes grinding in an automatic ball mill, as well as mixing and homogenization of a powdered sample weighing 1 g with binding Merck cellulose weighing 1 g. The study includes a method of mathematical planning of the experiment and data processing of the factorial experiment using the computer program “PlanExp B-D13” in a programming environment Microsoft Visual Basic 6.0.

The tablet was compressed using a Carver press. On an X-ray fluorescence spectrometer ARL ORTIM X 3, the sample was checked for the presence of basic and impurity elements. The obtained samples were studied using an SEM 100U scanning electron microscope. This helped to investigate more thoroughly the influence of grinding on the dispersibility of hydro-removal ash. To develop fine-grained concrete using hydraulic ash, an extensive experimental analysis of the initial components and samples based on them was carried out.

The strength and deformation properties of the MZB were studied on beam samples 4x4x16 cm in size, after their hardening – in baths with a hydraulic seal at a temperature (= 20 ± 2C). The compressive strength of sample cubes prepared from a high-density ash-cement binder and samples of beams prepared from an ash-cement-sand mortar corresponds to a normal consistency using hydro-removal ash with a size of 4x4x16 cm, determined at the age of 28 days on a German-made test press Testing Bluhm and Feuerherdt GmbH model CO89-04.

The dimensions of the finished samples were checked using a digital caliper, and the measurement range is 0-150mm. The mass of the samples was determined using an electronic balance of the VK-300 type, which guarantees increased measurement accuracy.

4. Results

The technical task of the invention is to reduce the cost of the mixture, accelerate the setting and hardening of the ash concrete mixture, and increase the strength and stability of the properties of the ash concrete, as well as expanding the areas of recycling industrial waste due to their additional use as active fillers in cement systems. Ash concrete can be used in various types of construction work, for example:

1. For the production of dense wall blocks, curbs, paving slabs.
2. For pouring the floor, screed and plaster.
3. For the construction of foundations, walls, ceilings, columns, balconies, etc.
4. For the production of soundproofing materials.
5. The use of fly ash concrete allows to significantly reduce the amount of cement used, which has a positive effect on the environment. Fly ash concrete also has high strength, durability and resistance to aggressive environments.

The chemical composition of the ash in the dumps of wet ash removal is not constant. For the manifestation of the pozzolanic properties of hydro removal ash, its activation is necessary, which is achieved by increasing the specific surface (grinding fineness) and adding liquid glass. Hydro removal ash contains only 10% free calcium oxide, as it is acidic. Unground acid ash has a heterogeneous chemical composition and water demand of up to 80%. With an increase in the specific surface area of acidic hydro-removal ash, the uniformity of the chemical and grain composition improves (substances obtained by crushing have the largest specific surface area).

It is necessary to evaluate activity at using ash in the composition of concrete. The method was used based on the ability of absorption by ash of hydro-removal of lime from lime mortar in this work (Figure 2).

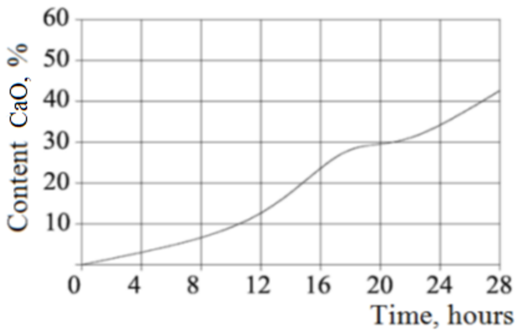

Fig. 2: Ash absorption by hydraulic removal of CaO from lime mortar

At using ash as an additive to cement, the most objective assessment of its activity can be the strength of such a binder, indirectly – the proportion of ash in the composition of the mixed binder, at which there is no decrease in the strength of the binder below the grade of the original binder without the addition of ash.

The requirements for ash as active mineral additives in the concrete mixture are determined by the physicochemical mechanism of their influence on the processes of hardening and structure formation of concrete. The hydraulic activity of ash, as well as other pozzolanic-type substances (consisting of mixtures of binder and mineral additives), is entirely due to the chemical interaction of silicon and aluminum oxides with calcium hydroxide, which is part of the substance. The reaction produces hydrates of calcium silicate and hydrates of calcium aluminate. Hydration of ash is promoted by its glassy phase; the number of glassy phases increases as the fraction decreases. The crystal phase, represented by components of quartz, mullite, hematite, and other elements, is practically not active in this process. The chemical activity of ash is also directly related to its dispersity, the use of finely ground ash improves the binding properties of the material[20].

The properties of the solution component are significantly affected not only by the physical and mechanical characteristics of all components, but also by the degree of their adhesion and interaction, the presence of cracks and pores both in the components themselves and along the boundary of their contact. The contact zone has a decisive influence on the deformation and strength properties of the solution. The strength of adhesion of hydro-removal ash with cement stone depends on humidity, content of coked particles, granulometric composition and limiting particle size. In the case of quartz sand, attention should be paid to the surface and type of sand, the presence of clay, dust particles and other factors.

Ash in concrete contributes to the formation of a denser structure of the intergranular space of aggregates and a less defective contact zone of aggregates with cement stone. This is due to a higher degree of cement hydration and the reaction between calcium hydroxide and ash components, with the formation of an additional amount of calcium hydrosilicate gel with a cryptocrystalline structure (Figure 3). The hydro-removal ash absorbs CaO from the calcium hydroxide solution according to the following chemical formula (1):

$$H_2O+SiO_2+Ca(OH)_2 \rightarrow CaOSiO3+H_2O. \quad (1)$$

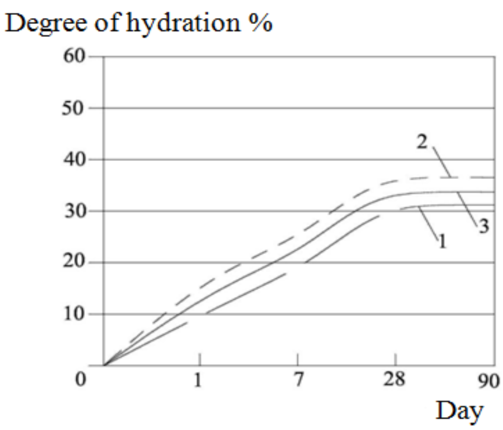

Fig. 3: Degree of hydration in cement stone ash

Note: 1 – without ash; 2 – 10% ash; 3 – 20% ash.

With a decrease in the concentration of calcium hydroxide in the liquid phase, the activity of the ash increases (Figure 4). This can be explained by the high content of the glass phase.

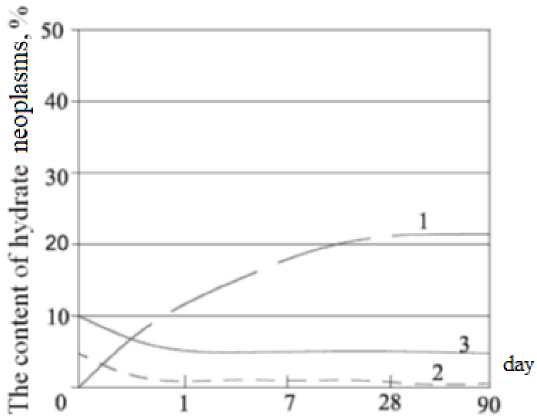

Fig. 4: Balance of hydrated new formation in ash-cement binder

Note: 1 – without ash; 2 – 10% ash; 3 – 20% ash.

The increased elasticity of ash-mineral materials is explained by the nature of the bonds formed during the hardening of the ash-mineral binder. In the structure of the ash-mineral stone, mainly gel-like neoplasms predominate, which cause hardening not due to direct intergrowth of particles, but through thin films of water. Only this can explain the increased elasticity of ash-mineral materials, noted by many researchers. The strength and deformation properties of fine-grained concrete were studied on beam specimens 4x4x16 cm in size, after their hardening – in baths with a hydraulic lock at room temperature ($t = 20 \pm 2C$). The determination of the strength characteristics of fine-grained concrete according to modern views[8], the products of the reaction of the binder with water cover the grains of the binder with a gel film, while between the shell and the grain of the binder there is a zone of an aqueous solution supersaturated with the products of the dissolution of the binder. The part of these products, mainly calcium hydroxide, diffuses through the shell and is located in the space between the particles of the binder. Over time, this zone is supersaturated with calcium hydroxide, which leads to the crystallization of portlandite. Predominantly, CSH is deposited on the inner part of the gel shell from the supersaturated solution, which causes the growth of the shell inside the cement grain due to its dissolution[11].

It was established that with an increase in the specific surface area of acidic ash from hydraulic removal to Srm = 200...250 m^2/kg, the number of aggregated particles significantly decreased, the uniformity of the grain composition of the ash increased by 32%.

For the experiment, samples were molded with a size of 7x7x7 cm and the composition: C:S = 1:3, ash – 10% of the mass of cement, the addition of liquid glass – 3% of the mass of cement, water – the rest. Based on the results of the experiment, it was revealed that an increase in the specific surface area of hydroremoval ash to Srm = 700...770 m^2/kg led to a decrease in compressive strength (Figure 5). Since aggregation due to surface forces increases with an increase in specific surface area, particles stick together at Ssp = 650...770 m^2/kg.

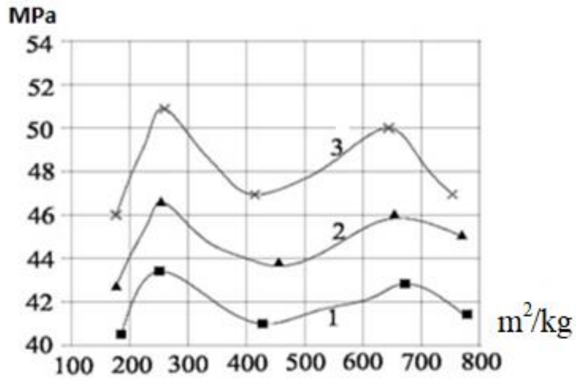

Fig. 5: Dependence of compressive strength on the hardening time and the specific surface area of the hydro-removal ash; the presence of ash – 10% of the mass of cement

Note: 1 – compressive strength for 28 days, MPa; 2 – the same, for 60 days, MPa; 3 – the same, for 90 days, MPa

Two areas of two sites are traced. It was found that the dependence on the specific surface area of hydro removal ash reached two maximum values. First area with an interval of Srm = 170...450 m2/kg and a maximum at Srm = 200...250 m2/kg characterizes the optimal packing of fine aggregate in fine-grained concrete, since the linear dimensions of the hydro removal ash particles approach the linear dimensions of sand particles (170…200 microns). The pozzolanic activity of the ash changes (as the grinding time increases, the activity increases). The decrease in strength at Srm = 250...450 m2 / kg occur due to the fact that the linear dimensions of the particles of hydro removal ash (80...50 microns) are approaching the linear dimensions of cement particles (50...60 microns). There is a decrease in the contact of cement particles with each other due to the filling of their intergranular space with ash particles, less water is spent on cement hydration.

The second area with an interval of Srm = 450...770 m2/kg and a maximum at Srm = 600...650 m^2/kg indicates that hydro-removal ash acts as a micro filler in the structure of cement stone At Srm = 450...650 m^2/kg, there is an increase in the difference between the linear particle sizes of hydro removal ash (5...50 microns) and cement (50...60 microns), the adsorption properties of the ash change during its dispersion, which leads to an increase in compressive strength.

Thus, the slow hardening of ash-cement concrete in natural conditions can be caused by various factors, such as the presence of hardening inhibitors in the ash, low calcium content, low ambient temperature and air humidity. Also, a possible factor may be the presence of impurities in ash-cement concrete, which can affect the distribution of ash and cement in concrete, which affects the hardening of the material. Different methods can be used to increase the rate of hardening of ash-cement concrete, such as increasing the concentration of calcium, using ultrasound, and other methods of activating hardening. The analysis of the obtained results showed that ash-cement concretes hardened slowly under natural conditions. At the period of 7-14 days of hardening, the strength of fine-grained concrete samples with the addition of hydro-removal ash is, as a rule, lower than the strength of reference samples without ash. The increase in the strength of samples at the age of 60 days was 6.6...7.0%, and at the period of 90 days – 15.0...15.5% compared with the strength of 28 days.

The addition of liquid glass additive to the ash-cement concrete mixture in the amount of 3% by weight of cement increases the compressive strength at the age of 28 days to 12...15% and accelerates the hardening processes up to 8...10% compared to the ash-cement concrete mixture without additives (Table 2).

Table 2. Test results of control samples

Physical and mechanical parameters	Concrete with liquid glass additive (3%)		
	10% ash	15% ash	20% ash
	S_{rm} = 200...250 m^2/kg		
Speed of ultra sound $V_{u.\ s}$ km/s	3.744	3.573	3.411
Bending strength R_{bn}, MPa	9.3	8.9	8.8
compression strength R_{st}, MPa	43.5	41.0	37.2
Average density of the concrete ρ_6, kg/m^3	2028	2148	2250

Ash in concrete contributes to the intergranular space of aggregates' dense structure formation and a less defective contact zone of aggregates with cement stone. This is due to a higher degree of cement hydration and the reaction between calcium hydroxide and ash components, with the formation of an additional amount of calcium hydrosilicate gel with a cryptocrystalline structure. A shell of neoplasms of calcium hydrosilicates appears around the ash particles. Above the surface of these shells, fibrous structures of the products of hydration of clinker minerals, more ordered than in the bulk of the cement stone, appear, elongated towards the surface of the ash particles. The structuring role of CHP ash lies in the formation of ordered fibrous structures. This effect is enhanced by increasing the specific surface area of the ash, fineness, and homogeneity.

The introduction of ash reduces the total pore volume of the cement stone and reduces the capillary porosity of the contact zone due to a significant decrease in the total $Ca(OH)_2$ content, but it is a slow process. Hydration changes the nature of the pores – capillary pores are filled with cement gel. At the same time, an increase in the content of calcium hydrosilicate in the immediate vicinity of the filler surface has a positive effect on the properties of the contact zone. In this regard, there is a positive effect on the microstructure of the contact zone with the introduction of a relatively small amount of ash from the Kazakhstan Thermal Power Station (TPS). The use of fine ash affects the packing density of neoplasms in the concrete structure. With an increase in the proportion of small particles in the ash, the packing density will increase due to the filling of capillary gaps with them, which naturally leads to an increase in density and an increase in the strength of concrete. However, as studies have shown, the specific surface of ash over 650 m^2/kg leads to a decrease in strength due to an increase in W/C.

Thus, the use of fly ash in the production of building materials can be environmentally effective and save resources, but it also requires quality control and attention to possible negative consequences. However, there are some potential disadvantages of using fly ash in the production of construction materials: the addition of fly ash can affect the strength and durability of concrete, which may require additional quality control costs; fly ash can have different composition and properties depending on the source from which it was obtained, which can lead to uneven properties of construction materials made from ash; although the use of ash can be environmentally effective by reducing the amount of waste associated with cement production; fly ash can only be used in limited quantities in building materials, as its addition can affect the properties of concrete and other building materials.

It is worth noting that the use of ash in the production of crushed stone has several environmental advantages compared to traditional methods, such as:

1. Economy of cement. Using fly ash in concrete reduces the amount of cement that is produced, using a lot of energy and natural resources. This reduces emissions of harmful substances into the atmosphere and reduces the negative impact on the environment.
2. Waste processing. Ash is a waste in the production of electricity from coal, and its use in the production of concrete allows reducing the amount of waste and reduce the negative impact on the environment.
3. Reducing the consumption of natural resources. The use of ash in the production of crushed stone allows to reduce the consumption of natural resources, such as sand and stone, which are components of traditional production methods.
4. Reduction of CO_2 emissions. Cement production is one of the main sources of greenhouse gas emissions, particularly CO_2. The use of ash in concrete allows reducing the amount of cement used, which in turn reduces CO_2 emissions.

5. Discussion

Analyzing the results obtained in the previous section, the main provisions can be highlighted. The chemical composition of CHP ash waste in wet ash disposal dumps is not always constant. For ash from the wet ash removal system of a thermal power plant, mechanical and chemical activation is required by increasing the specific surface area (grinding fineness) and introducing liquid glass additives to display additional pozzolanic properties of hydro removal ash. In the course of the experiment, the optimal content of hydro-removal ash (10% by weight), its fineness (200-250 m/kg), and the amount of liquid glass additive (3% by weight) were established, which ensures the production of fine-grained concrete with high-performance properties. And also, a technology for producing fine-grained concrete with a hydro-removal ash content of 10% by weight is proposed.

The topic under study is relevant for the near future and is the object of study by researchers from different countries. In the process of work, projects, technological schemes, and regulations for the complex processing and use of ashes, slags from thermal power plants, slags from foundries, and other industrial wastes in fine-grained concrete for various purposes (Ukraine, Kazakhstan, Poland, Germany, etc.) were studied.

The works which resulted in similar conclusions are discussed below. In the course of the analysis, aspects of the modification of the concrete mixture due to non-deficient fillers based on ash and slag waste (fly ash from thermal power plants) were considered[21-23]. The ashes of thermal power plants are formed during the combustion of pulverized coals. Glassy ash particles are deposited in electrostatic precipitations and then removed from the dry (fly ash) or wet (hydraulic ash). Fly ash usually has higher properties, differing in the quality of raw materials and chemical composition.

The general properties of the materials obtained as a result of the in tests the works of J. James et al.[22], Z. Qu et al.[23], M. Amran et al.[24] are the high dispersion of ash, and the fusion of particles of various granulometry, which positively affect the workability of the concrete mix. Used methods of mechanical and mechanochemical grinding. Ash pre-treatment by grinding, magnetic separation, and flotation increases its reactivity, which combines all the studies below. Ashes can have differences in chemical composition (acid (K) – anthracite, coal, and lignite, containing calcium oxide by weight up to 10%; basic (O) – lignite, containing CaO of more than 10%). Basic ash with a CaO content of at least 30% is recommended to be used as a mineral additive in cement or a component of another binder in the manufacture of building concretes and mortars. Different amounts of ash are introduced into each of the control concrete compositions, various chemical additives are used.

The studies that were carried out by scientists T. Mukhammed[25)] on the fly ash of the Angren State District Power Plant are of special interest. Fly ash is a finely dispersed product consisting of small spherulites, inside glass droplets of which there are hydraulically active minerals, opened at mechanical activation. The main component of 65% is the vitreous aluminosilicate phase in the form of spherical particles ranging in size from 0.001 to 0.14 mm. It is they who show the greatest hydraulic activity, that is, the ability to harden due to the binding of CaO. In the works of T. Mukhammed[25)] it is suggested to add fly ash to concrete in an amount of 10-15% to improve the quality of concrete and to save cement. In the research work, fly ash from Angren TPP with a dispersion of 3500 cm2/g was used. The experiment showed that the introduction of fly ash into concrete reduced shrinkage deformation, creep, and heat release during hardening. To accelerate the curing process in the initial period, a plasticizing surface-active additive (water-soluble resin SAFA) is introduced into the concrete mortar, which increases the adhesion and elasticity of the mortar. The experiment showed that the combined use of fly ash with superplasticizers gives excellent results and ensures early strength of high-strength concrete compositions together with cement saving. The frost resistance of the material increases up to 200 cycles, a consequence of the air content of concrete increasing by 3-4%[25)]. Scientists P. Janardhan and V. Krishnaiah[26)] conducted similar tests and concluded that by increasing the level of GGBS replacement, the strength of geopolymers increases.

A known method for producing ash concrete mixture is by mixing Portland cement, fly ash, and sand, while sand is first mixed with fly ash, then cement is introduced, and, after secondary mixing, mixing water. The final mixing of the concrete mixture is brought to a homogeneous state. Fly ash is introduced instead of part of the sand. This method is mentioned in the works of B. Jaworska et al.[27)], Y. E. Wu et al.[5)]. However, the disadvantage of this method is its low strength and large plastic deformation of concrete.

Let us analyze another valuable work of American researchers H. Sung and R. Shahsavari[28)]. The Journal of the American Ceramic Society published the work of engineers from Rice University (USA), who created eco-friendly concrete without cement, which is not inferior in strength to a standard analog. The value of the project is based on the use of type C ash with a high calcium content, which was activated despite the complexity of the process. Using the static Taguchi method, the optimal composition of substances was determined, and a balance was found between ash, silicon dioxide, calcium oxide, and a 5% sodium-based activator.

An analysis of the literature on the use of ash from thermal power plants allows making a conclusion that most of the work is based on the production of ash-cement compositions with the introduction of various additives and the use of high-speed mixing (rotary-pulsation devices)[22-28)]. With the introduction of ash, the structure of concrete changes markedly. A new binder component appears in the solid frame – ash, which differs in properties from cement. A new structural element appears – the product of the pozzolanic reaction, and the ratio between the gel and crystalline components in neoplasms changes. The porosity of the cement stone increases. In practice, fly ash is used to reduce the consumption of cement and aggregates, improve the technological properties of concrete and mortar mixtures, and improve the quality of concrete and mortar.

Research papers with other aspects and differences in approaches were also studied, which will be discussed in this part. Namely, the study of the use of various chemical additives that affect the physical and technical properties of the created concrete. These aspects were considered in the works of A. Siddika et al.[29)], M. Amran et al.[30)], K. Ohenoja et al. [31)], K. Chen et al.[32)], N. M. Morozov et al.[33)], L. Lei et al.[34)], J. Zhang[35)]. The use of chemical additives in concrete technology is based on fundamental research in the field of physical and chemical surface phenomena and contact interactions in dispersed systems, which were laid down in the works of P. A. Rebinder[36)].

In the work under study by N. M. Morozov et al.[33)] the joint work of hyper plasticizers and fine filler to improve the properties of fine-grained concrete was investigated. The use of Melflux 2651F and Glenium ACE 430F additives in combination with silica fume/ground quartz sand increases the strength of fine-grained concrete and reduces its water absorption.

The increase of concrete strength occurs in the zone of its contact with the aggregate, due to the reduction of the water-cement ratio and capillary porosity of the contact zone due to a sharp decrease in $Ca(OH)_2$ content[37-39)]. These material properties are common for the investigated by us ash-cement concrete and fine-grained concretes based on complex additives from superplasticizers and are described in the works of N. M. Morozov et al.[33)], L. Lei et al.[34)], J. Zhang et al.[35)]. However, in the variant under study by us the cost of the initial material will be cheaper, the project is economically more profitable, and the problem of disposal of waste of man-made origin is solved.

It should be noted that at large power plants, it is necessary to provide facilities for the collection and processing of ash and ash-and-slag mixtures for further supply of products to consumers[40-42].

The use of a variety of the material under study with the use of large-tonnage production waste is widely used in practice. For example, cement slurries with the addition of chalk, shale ash, and crushed coal have been developed in Ukraine. JSC KazNIGRI uses lightweight types of cement with the addition of fly ash, expanded clay dust, and crumb rubber. In the production technology of materials, the use of ash and slag made it possible to reduce sand and cement by up to 20%[43, 44].

Materials based on ash and slag waste are widely used in world construction practice. In Italy, Japan, India, and the USA, ash is used as a natural filler and binder in pavement structures. In China, a mixture of lime with coal ash (lime: ash = 1:4) was used as a carrier layer in the construction of a highway. On the Nanjing-Yancheng expressway, soil reinforced with a complex binder (cement, lime, and fly ash) was used as the base of the pavement. As a binder and active additive in pozzolanic concrete, fly ash is used in Belgium.

Summarizing the above, the main points of the study can be resumed. In this section, projects for the complex processing and use of ashes, slags from thermal power plants, and other industrial wastes in fine-grained concrete were analyzed. General aspects of the modification of the concrete mixture based on ash and slag waste were identified [22-28]. It was determined that with an increase in the proportion of small particles in the ash, the density will increase due to the filling of capillary gaps with them. Replacing part of the cement with ash leads to a reduction of concrete shrinkage by reducing the water demand of the concrete mixture. The ash adsorbs soluble alkalis from cement, forming stable insoluble aluminosilicates, strengthening the structuring role of the filler and consequently reducing the shrinkage of the material[45, 46]. Long-term load tests of concrete have shown that the introduction of ash also reduces the creep of concrete. Ash, like other active mineral additives, improves the corrosion resistance, including the sulfate resistance of cement concrete, and increases their water resistance.

6. Conclusions

The balance of hydrate formations in ash-cement was determined. At the same time, it was found that with an increase in the specific surface area of acidic ash from hydraulic removal to Srm = 200...250 m^2/kg, the number of aggregated particles significantly decreased, and the uniformity of the grain composition of the ash increased by 32%.

The dependence of the compressive strength on the hardening time and the specific surface of the hydro-removal ash has been studied and investigated; the presence of ash – 10% of the mass of cement.

Analysis of the obtained results showed that ash-cement concretes harden slowly under natural conditions. At the period of 7-14 days of hardening, the strength of fine-grained concrete samples with the addition of hydro-removal ash is, as a rule, lower than the strength of reference ones without ash. The increase in the strength of samples at the period of 60 days was 6.6...7.0%, and at the period of 90 days – 15.0...15.5% compared with the strength of 28 days.

Ash-cement stone has a number of advantages – increased frost resistance, increased water resistance, and reduced water absorption. The modulus of elasticity can be varied by changing the composition of the ash. The modulus of elasticity of the gold-cement stone is in the range of 4000 to 7500 MPa, showing an increased elasticity of the stone, which is due to the predominance of gel-like neoplasms in the structure of the stone.

The obtained research results indicate the possibility of using ash in the production of fine-grained concrete for low-rise construction of buildings and structures with various functional purposes: for solid wall blocks, paving slabs, for pouring floors, and also as a masonry mortar.

The use of hydro-removal ash as an additive will reduce the deficiency of components in the material and improve the ecological environment, as it is a large-tonnage waste. Also, the introduction of ash into the concrete mix improves workability and helps to reduce the water separation of the concrete mix. Concrete mixtures with the optimal addition of ash have sufficiently high viability and are suitable for transportation over long distances.

The results of this study may be useful in understanding the properties of concrete containing Kazakhstan fly ash and liquid glass, but the application of these findings to other types of fly ash or similar materials for use in concrete production requires further investigation. Different types of fly ash can have different physicochemical properties that can affect their effectiveness as a concrete admixture. Other parameters, such as granulometry, chemical composition, etc., may also differ. Therefore, separate studies are needed for each type of fly ash to understand their effect on concrete properties.

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