IRSTI 67.09.05

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https://doi.org/10.55956/QHFC1264

INFLUENCE OF THE W/S RATIO ON THE CELLULAR CONCRETE PROPERTIES ON THE BASIS OF FLY ASH

Abstract. The article considers the results of a study of fly ash from the Ekibastuz coal basin in the production of cellular concrete. Studies have shown that the composition of fly ash is very complex in terms of the variety of chemical elements and its use as a siliceous component instead of sand has a beneficial effect on the value of the W/S ratio. A study of the pore structure of cellular concrete showed that an increase in the W/S ratio leads to a sharp change in the nature of the porous structure, that is, the higher the W/S, the higher the quality of its porous structure. However, an excessive increase in W/S causes stratification of the solution. In order to establish the optimal value of the W/S ratio using fly ash, studies were carried out. The results of a study to determine the influence of the porous structure of cellular concrete on its properties clearly showed how, with increasing W/S ratio, the porosity deviation index decreases, and the lower the porosity deviation, the better the characteristics of the macropores of cellular concrete, and accordingly, the higher the strength of aerated concrete.

Keywords: cellular concrete, fly ash, siliceous component, W/S ration, gas ash concrete, autoclaved hardening, pore structure.

Mominova S., Kopzhasarov B. Influence of the W/S ratio on the cellular concrete properties on the basis of fly ash // Mechanics and Technologies / Scientific journal. – 2024. – No.2(84). – P.167-174. https://doi.org/10.55956/QHFC1264

Introduction. Ekibastuz coal fly ash is very refractory, T_{ref}=1670-1720 °C, it is due to the high silica content in its composition. Due to the excessively high refractory temperature of the fly ash and the insufficient maximum temperature of the gases in the furnace (1500-1550 °C), some fly ash particles do not melt and have an irregular shape with sharp edges [1].

The thermal power plant fly ash, freed from organic substances, was studied microscopically. It was found that vitrification and crystalline phases represented by feldspar, calcite, quartz and, in smaller quantities of magnetite, corundum, hematite, amorphized clay components and other minerals are the main components of the phase composition.

The vitrification is a product of thermochemical action on the mineral part of the fuel (mainly clay). Research has showed the ideally pillow-like or fairly spherical (solid or hollow) shape of most vitrous fly ash particles. In addition, scale-like and cellular forms are distinguished. Often the particles are presented as a inflated mass. The amorphous phase of the fly ash is heterogeneous, represented by two types of glass, colorless and in the form of melted balls of yellow and yellow-brown color due to the presence of iron oxide in it. The surface and contours of colorless balls are mostly unclean and corroded, while yellow and yellow-brown colored balls are smooth, clean, and less likely to be subject to mild corrosion. The glass beads contain feldspar, magnetite, hematite, clay particles and sometimes quartz grains. The crystalline part of the fly ash appears to be both primary minerals accompanying the organic part of the fuel, and new formations obtained in the combustion process. The main crystalline parts of the fly ash include quartz, feldspar, mullite, magnetite, hematite, calcite, dolomite and cristobalite.

Researchers note that the fly ash of dry separation from the Ermakovskaya State District Power Plant consists of 10-15% aggregated accumulations, represented by colorless isotropic claw-shaped plates. These plates contain up to 10% point like anisotropic inclusions, represented by incompletely crystallized mullite, and a significant amount of about 5% grains and mullite needles. The aggregate mass contains rare grains of cristobalite and tridymite [2].

Therefore, it is clear that the composition of fly ash is very complex in terms of the variety of chemical elements present in it, the combination of various compounds, the shape and nature of the surface, and much more, all this necessitates a thorough study of the properties of cellular concrete in the production of which fly ash from coal combustion in the Ekibastuz coal basin is used as a siliceous component.

As is known, the physical, technical and performance characteristics of cellular concrete depend on a number of factors and, first of all, on the composition, their ratio, the amount of water mixing, density, structure, heat treatment mode and on the type and properties of the primary materials.

Conditions and methods of research. The use of fly ash as a siliceous component significantly affects the optimal W/S ratio value, on which the basic properties of gas ash concrete largely depend. The optimal W/S ration value is understood as the ratio of the weight of water to the weight of dry components at which the rate of increase in the structural viscosity of the gas-ash concrete mixture would correspond to the rate of the gas release process. If the W/S ratio is insufficient, the plastic viscosity increases quickly and the gas-ash concrete mixture has time to completely blow up. The resulting gas bubbles accumulate in the solution and, due to the ever-increasing lifting force, encountering resistance, break the viscous gas-ash concrete mixture, forming a network of cracks, which greatly reduces the final strength. The structure of gas ash concrete under these conditions is defective, and gas use is low.

If W/S ratio value is excessive, the plastic viscosity of the gas-ash concrete mixture increases slowly and by the time it is finished, the gaseous flowability of the solution remains high, while many gas bubbles float to the surface, water separation occurs, the mass boils and settles.

The rate of increase in the plastic viscosity of a gas-ash concrete mixture of a given composition depends on the water content and temperature of the gas-ash concrete mixture.

This can be explained by the fact that with an increased water content of the gas-ash concrete mixture, a better and more uniform structure of cellular concrete is obtained.

The flowability of gas ash concrete decreases significantly with increasing temperature of the mixture (Table 1).

Table 1

Influence of W/S ration on flowability of gas ash mixture

W/T	Flowability of mixture, according to the Suttard viscosimeter (sm)	
	Temperature 13°C	Temperature 40°C
0.55	15	11
0.62	22	19
0.68	26	24
0.75	30	30

The reason of this is that the process of hydration of lime and cement is accelerated at high temperature and water is quickly absorbed by cementitious materials. Lime hydration occurs much faster than cement. As the W/S ratio value increases, this difference gradually decreases and at W/S = 0.75 the flowability remains the same and does not depend on the mixture temperature. A study of the pore structure of cellular concrete showed that an increase in the W/S ratio, all other things being equal, leads to a sharp change in the nature of the porous structure from pore aggregates elongated in the form of an ellipse (which have a higher stress concentration than spherical pores) to pores of regular shape with clear outlines. When studying macroporous cellular concrete, pores of regular spherical shape (large W/S ratio), with clear outlines showed less deviation in porosity value and, accordingly, greater strength.

That is, with an increase in W/S ratio, the quality of its porous structure improves. Consequently, the positive role of increasing W/S ratio is to reduce the viscosity of the mortar mixture and, thereby, improve the conditions for the flowability of the spherical shape and their uniform distribution throughout the entire volume of this mixture. However, an excessive increase in W/S causes stratification of the solution. Excess water settles on top and pours out of the molds when the gas ash concrete swells, and the binders somewhat reduce their activity.

If W/S ratio is higher, the mixture blows out well, but sets slowly, resulting in “boiling”, the gas evaporates, and the mixture settles. Therefore, we accepted the optimal values of the water-solid (W/S) ratio such that there is no thawing of water on the surface of the solution, without adding a gas-forming agent in it.

If the W/S ratio increases from 0.6 to 0.65, it is noted that at the W/S ratio of 0.6 the mixture blew out well, and with an increase of the W/S ratio to 0.65 at other things being equal, partial sedimentation of water and rapid blowing out occurred with the mixture pouring out of the walls of the molds, and the pore structure has an elongated and partially stuck together character, which differs significantly from the optimal structure.

To obtain the optimal structure of gas ash concrete, along with the temperature and the viscosity of the mixture, when the pores in the concrete are spherical and spead evenly, the quality of the selected type of gas-forming agent plays an important role, and it is also necessary to achieve a coordinated interaction between the kinetics of increase in structural viscosity and the kinetics of gas emission.

In this regard, the pores formed by the gas have different sizes, as a result of which the gas-ash concrete may turn out to be heterogeneous.

The smaller the pores and the more equal their spreading in the concrete, the higher the quality of gas ash concrete in terms of uniformity of properties (in terms of strength and density of concrete) and, no less important, in terms of thermal conductivity, this is achieved by using smaller petals of aluminum powder. To do this, crushed aluminum powder is obtained by vibrating the powder together with ash.

In technological environments, the quality of the supplied aluminum powder in terms of uniformity of granulometry largely depends on the supplier's plant.

In order to define the optimal value of the W/S ratio using fly ash, studies were carried out on gas ash concrete with a density of 600 kg/m^3. The defined optimal ratio of the silica component to the binder (C) in terms of strength was 1.2. At the optimal temperature of the gas-ash concrete mixture, equal to 40-45 °C, the addition of 3.0 kg per m^3 of concrete, semi-aqueous gypsum ($CaSO_4 \cdot 0.5H_2O$), significantly improved the rheological characteristics of the mixture. The steaming regime was carried out according to the previously defined rational regime of 3+6+3 hours at a temperature of 90±5 °C.

As can be seen from Table 2, with an increase of the W/S ratio, the strength of gas ash concrete increases, and the optimal value of the W/S ratio in terms of strength in our case is taken to be 0.60, while with a W/S ratio equal to 0.65 partial sedimentation of water occurs and rapid swelling and partial pouring of the mixture along the edges of the molds is observed.

The value of the optimal water-solid ratio is influenced by the water-need of the mortar mix, which, at a constant ratio of the silica component to the binder (C), depends on the properties of the primary materials. Thus, the porous components of fly ash have a greater water-need, and when grinding fly ash, the porous structure is disrupted and the water-need of the gas-ash concrete mixture decreases [3].

In the technology of cellular concrete, there are technological methods that make it possible to ensure the necessary rheological properties of the cellular concrete mixture, while increasing the W/S ratio. Thus, it is possible to reduce the viscosity of the mixture using complex vibration, during its blowing out and obtain cellular concrete with a high-quality macroporous structure at reduced water-solid ratios. In order to reduce the water-solid ratio in cellular concrete, many researchers have undertaken a variety of methods, but the use of super-fluidizing agent C-3, as shown in factory tests (at Pavlodar Reinforced concrete structures plant-4), showed that the effect of liquefying the mixture, which is observed in similar conditions during operation with heavy concrete was not achieved. In all likelihood, the features inherent in cellular concrete, and first of all, the blowing out of the mixture, and not its compaction, which we have in heavy concrete, imposes its effect [4].

Studies of the properties of cellular concrete in the laboratory of Research, Design and Technological Institute of Concrete and Reinforced Concrete showed that with an increase of the W/S ratio, the compressive strength doubles, and the dynamic modulus of elasticity (DMU), determined by the resonance method, and the speed of ultrasonic waves almost do not increase. Thus, it turned out to be possible to evaluate the increase in the elasticity of the intercavity material and the increase in strength due to an increase in the quality of the porous structure, revealing the primary role of the structure of the vapor space of cellular concrete [5]. The macroporous structure in cellular concrete is formed mainly by a blowing agent. The number of such pores in cellular concrete makes up the majority and it is the macroporous structure as a whole that determines the density of cellular concrete and has a significant impact on its properties. For the first time, the qualities of a macroporous structure began to be determined using a photoelectronic installation created by A.P. Filin under the supervision of G.A.

Logginov on the basis of a binocular microscope. The photoelectronic setup made it possible to study the surface spread of porosity, as well as the pore size spreading. At the installation, the total porosity was measured by the amplitude of the photocurrent, the value of which was noticeably distorted due to the instability of the photomultiplier or the network voltage. Difficulties in work are also caused by the complexity of preparing samples for testing; along with careful grinding of the sample, it was necessary to paint the surface with white enamel and fill the pores with carbon black [6].

Employees of the Department of Physics of MSCU, together with the Research, Design and Technological Institute of Concrete and Reinforced Concrete due to the existing photoelectronic installation, created a more advanced photoelectronic installation and developed a method for determining the quality of the macroporous structure of cellular concrete [7].

A photoelectronic installation for determining the quality of the macroporous structure of cellular concrete consists of a position table with an electric drive, an illumination system, an optical projector, and a photomultiplier with a cascade voltage divider.

This system makes it possible to compare the quality of the macroporous structure of cellular concrete samples. Quality assessment is made by the standard deviation of surface porosity, which is measured on a flat section of a porous material by circular scanning of the latter.

The standard deviation of surface porosity is determined by the readings of a pointer electric meter (voltmeter) of effective values, which ensures the speed of the information obtained.

Determination of the quality of the macrostructure of gas ash concrete with different W/S ratios is given in Table 2.

Table 2

Influence of the W/S ratio on the strength of autoclaved gas ash concrete

Compo-sition	W/TS	Flow according to the Suttard	Mixture temperature	Density	Compres-sive strength	Deviation of porosity value
		sм	°C	кg/m^3	MPa	Eph
1	0.5	15.0	40	606	1.72	0.175
2	0.55	16.0	40	610	2.12	0.163
3	0.6	16.5	40	613	2.63	0.133

Research results. The results of studies to determine the influence of the porous structure of cellular concrete on its properties clearly showed how, with an increase in the W/S ratio from 0.50 to 0.60, the porosity deviation index – Eph (the standard deviation of the porosity surfaces of cellular concrete and is determined by the readings of a pointer electric meter) decreases device – a voltmeter of effective values) from a value of 0.175 to 0.133, respectively, and the smaller the deviation of the porosity value – Eph, the better the characteristics of the macropores of cellular concrete (the pores are round and give little light scattering and are evenly distributed over the body of the concrete) and, thus, correspondingly higher strength of gas ash concrete. Many foreign researchers indicate the significant influence of the nature of the pore structure on the properties and operational durability of products made from cellular concrete.

Thus, it has been established that in order to obtain strong and resistant gas ash concrete of any density, it is necessary to ensure, first of all, the coordinated interaction of the processes of gas formation and blowing up with the process of gaining plastic strength and, accordingly, obtaining a high-quality macroporous structure.

When working with new components of gas ash concrete, such as fly ash from state district power plants, the composition of the mixture is usually established experimentally based on test results, but taking into account numerous studies of various ashes and data on optimal compositions and modes.

Studying the nature of the dependence of the strength of gas ash concrete on the composition is of great practical importance, since it allows one to find maximum strength with the lowest consumption of binder.

Studying various compositions with ash, recommended by researchers, simple and available in production conditions, additives, in the process of our experimental work, we found that using a mixed binder (cement-lime) in a ratio of 4:1 with the addition of up to three kg per m^3 to the mixture, semi-aqueous gypsum $CaSO_4 \cdot 0.5H_2O$, water-solid ratio 0.60, at a temperature of the gas-ash concrete mixture equal to 40-45 °C, allows us to achieve a coordinated interaction of the processes of gas formation and blowing up with the process of gaining plastic strength, to obtain high-quality autoclaved gas-ash concrete with an optimal porous structure. The ratio of the silica component to the binder is 1.2. At the same time, it is possible to obtain autoclaved gas ash concrete B4 without consuming more than 200 kg/m^3 of Portland cement per m^3 of gas ash concrete with a density of 600 kg/m^3.

Discussion of scientific results. Research in order to determine the influence of the type of siliceous component on the properties of cellular concrete has shown that in non-autoclaved production of gas-ash concrete (steaming according to the mode of 3+6+3 hours at a temperature of 90±5 °C), gradual replacement of sand with a specific surface area of 2500 sm^2/g, on fly ash with a specific surface area equal to 2800-3000 sm^2/g, leads to a significant increase in strength from 0.83 MPa to 2.34 MPa, that is, when completely replacing sand with fly ash, we get maximum strength results, that is, non-autoclaved grade B2 gas-ash concrete based on acidic fly ash obtained from burning coal from the Ekibastuz coal basin.

Research with autoclaved gas ash concrete, steamed in a mode of 2+8+2 hours at a pressure in the autoclave of 0.8 MPa and a temperature of 174.5^0C, which, other things being equal, autoclave treatment gives high strength indicators and a grade of gas ash concrete equal to B2.5-B4.2 at a density of gas ash concrete equal to 600 kg/m^3.

Moreover, the data indisputably shows that in the case of using autoclave treatment, maximum strength is achieved when a mixture consisting of fly ash and lime is used, and, with a ratio of 1:1, this very extraordinary phenomenon can be explained by examining the obtained new formations. Thus, studying the type of the strength dependence on the composition of gas ash concrete, researchers note that at maximum strength, the phase composition of new formations is characterized by the disappearance of $C_2SH(A)$ and the formation, in addition to CSH(B), of lamellar crystals such as tobermorite $C_4S_5H_5$ and xonotlite. The decrease in strength from increasing the addition of fly ash beyond the optimal composition occurs, in their opinion, mainly due to the dilution of the cementitious binder with unreacted ash particles.

In the case of non-autoclave technology, we had maximum strength with the complete replacement of sand with ash, which indicates the high activity of the most acidic fly ash, while the main cementing factor remains compounds formed by hardening cement products.

Conclusion Thus, we confirm the fact that ashes have increased hydraulic activity during their complex lime-gypsum activation [8].

Based on this, it seems to us that it is primarily necessary to take advantage of such properties of acidic fly ash as ours obtained from the combustion of coal from the Ekibastuz coal basin in the production of autoclaved gas ash concrete.

The strength of autoclaved cellular concrete on sand had a maximum of 3.42 MPa, and on fly ash – 3.9 MPa, while with a sand:fly ash ratio equals to 1:1, the strength was 4.15 MPa.

References

1. Zimanova G.A., Solonina V.A., Bayanov D.S., Ilyasova S.V. E`ffektivnost` toplivny`kh zol uglya E`kibastuzskogo bassejna v czementny`kh sistemakh [Efficiency of coal fuel ash from the Ekibastuz basin in cement systems]. M.: Innovations and investments, 2019. – 327-330 p., [in Russian].
2. Abdrakhimov V.Z. Stroitel`ny`e keramicheskie materialy` na osnove otkhodov czvetnoj metallurgii, e`nergetiki i netradiczionnogo prirodnogo sy`r`ya [Construction ceramic materials based on waste from non-ferrous metallurgy, energy and non-traditional natural raw materials]: Abstract of the dissertation for the degree of Doctor of Technical Sciences. Ust-Kamenogorsk, 2002. – 61 p., [in Russian].
3. Esmaily H., Nuranian H. Non-autoclaved high strength cellular concrete from alkali activated slag // Construction and Building Materials, 2012. Vol. 26. No. 1. P. 200-206.
4. Akhmetov D.A., Akhmetov A.R. Povysheniye stoikosti plotnosti i prochnosti yacheistobetonnykh izdeliy [Increasing the durability density and strength of cellular concrete products] // NPZH «Arkhitektura, stroitel'stvo, dizayn» [Scientific and practical journal "Architecture, construction, design"], 2006. No. 1, [in Russian].
5. Akhmetov A.R., Akhmetov D.A. Izdeliye iz yacheistogo betona - effektivnyye materialy dlya seysmostoykogo stroitel'stva [Cellular concrete products are effective materials for earthquake-resistant construction] // Vestnik Nats. Inzhener akademiy RK [Bulletin of the National Engineer of the Academy of the Republic of Kazakhstan], 2000. No. 1 (5), [in Russian].
6. Mominova, S.M., Kopzhasarov, B.T., Sadykov, ZH.A. Tekhnologiya gazosilikatnogo betona s ispol'zovaniyem promootkhodov i nekonditsionnogo syr'ya [Technology of gas silicate concrete using industrial waste and substandard raw materials] // Vestnik Kazakhskoy golovnoy arkhitekturno-stroitel'noy akademii [Bulletin of the Kazakh Head Academy of Architecture and Construction], 2019. No. 4 (74). P. 214-220, [in Russian].
7. Akhmetov A.R., Bisenov K.A., Kuatbayev K.K. Sovremennoye sostoyaniye i perspektivy proizvodstva yacheistogo betona v Kazakhstane [The current state and prospects of cellular concrete production in Kazakhstan]. ¬ Almaty: Science, 1998. [in Russian].
8. Ismailov A., Baybolov K., Ristavletov R., Kopzhasarov B., Kambarov M., Ussipbayev U., Mominova S. Effect of cost-effective alkaline additives on the hydration of slag-cement mixtures // Journal of Advanced Concrete Technology, 2018. Vol. 16. No. 9. P. 429-440.

The article was prepared under the project AP19175553 "Development of energy-saving technology for producing autoclaved cellular concrete using fly ash from thermal power plants and natural wollastonite" as part of the implementation of research work on a state order (contract date May 17, 2023, 149-ZH-4).

Material received on 16.04.24.

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СУДЫҢ ҚАТТЫ ЗАТҚА ҚАТЫНАСЫНЫҢ ЖЭС ҰШҚЫН КҮЛІН ПАЙДАЛАНА ОТЫРЫП ӨНДІРІЛЕТІН АВТОКЛАВТЫ ҰЯЛЫ БЕТОН ҚАСИЕТІНЕ ӘСЕРІН ЗЕРТТЕУ

Аңдатпа. Мақалада ұялы бетон өндірісінде пайдаланылған Екібастұз көмір бассейнінің ұшқын күлін зерттеу нәтижелері қарастырылады. Зерттеулер көрсеткендей, күлдің құрамы химиялық элементтердің әртүрлілігінің арқасында өте күрделі және оны құмның орнына кремний топырақты компоненті ретінде қолдану судың қатты затқа қатынасына жағымды әсер етеді. Ұялы бетонның кеуек құрылымын зерттеу судың қатты затқа қатынасының жоғарылауы кеуекті құрылымның сипатының күрт өзгеруіне әкелетінін көрсетті, яғни судың қатты затқа қатынасы неғұрлым жоғары болса, оның кеуекті құрылымының сапасы соғұрлым жоғары болады. Дегенмен, судың қатты затқа қатынасының шамадан тыс жоғарылауы ерітіндінің қатпарлануына алып келеді. Ұшқын күлді қолдана отырып, судың қатты затқа қатынасының оңтайлы мәнін анықтау мақсатында зерттеулер жүргізілді. Ұялы бетонның кеуекті құрылымының оның қасиеттеріне әсерін анықтау бойынша зерттеу нәтижелері судың қатты затқа қатынасының өсуімен кеуектіліктің ауытқу көрсеткіші қалай төмендейтінін анық көрсетті, ал кеуектіліктің ауытқуы неғұрлым аз болса, ұялы бетонның үлкен кеуектерінің сипаттамасы соғұрлым жақсы болады, сәйкесінше газ күлбетонның беріктігі жоғары болады.

Тірек сөздер: ұялы бетон, ұшқын-күл, кремнийтопырақты компонент, судың қатты затқа қатынасы, газкүлбетон, автоклавта қатаю, кеуектердің құрылымы.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ В/Т ОТНОШЕНИЯ НА СВОЙСТВА АВТОКЛАВНОГО ЯЧЕИСТОГО БЕТОНА С ИСПОЛЬЗОВАНИЕМ ЗОЛЫ-УНОСА ТЭС

Аннотация. В статье рассматриваются результаты исследования золы-уноса Экибастузского угольного бассейна при производстве ячеистого бетона. Исследования показали, что состав золы-уноса очень сложный по разнообразию химических элементов и применение его в качестве кремнеземистого компонента вместо песка благоприятно влияет на величину В/Т отношения. Изучение структуры пор ячеистого бетона показало, что увеличение В/Т отношения приводит к резкому изменению характера пористой структуры, то есть чем выше В/Т, тем выше качество его пористой структуры. Тем не менее, чрезмерное повышение В/Т, вызывает расслоение раствора. С целью установления оптимального значения В/Т-отношения с применением золы-уноса, были проведены исследования. Результаты исследования по определению влияния пористой структуры ячеистого бетона на его свойства наглядно показали, как с ростом В/Т отношения уменьшается показатель отклонения пористости, а чем меньше отклонение пористости, тем лучше характеристика макропор ячеистого бетона, соответственно выше прочность газозолобетона.

Ключевые слова: ячеистый бетон, зола-унос, кремнеземистый компонент, В/Т отношение, газозолобетон, автоклавное твердение, структура пор