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GAS SILICATE CONCRETE BASED ON ACTIVATED WASTE ENERGY

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ABSTRACT: Ash and slag dumps represent valuable secondary raw materials, though currently underutilized, leading to significant storage costs. Utilizing these materials involves several challenges, including advancing gas-silicate composition and improving production technology. This research presents findings on the fractional composition of ash and slag wastes, which are used as fillers in gas-silicate production. Due to significant variations in the chemical composition, fraction sizes, and structure of these wastes, mechanical processing is needed to stabilize their properties. The glassy surfaces of ash particles hinder binder hydration, so component activation—particularly of autoclaved gas silicate (using sand, slag, and dry-selected ash)—has been explored. A technology has been developed to activate these components with an aluminous additive. Optimal compositions of gas-ash and gas-slag silicates were determined. The study examined the effects of replacing a portion of Portland cement with activated fly ash or slag in the presence of an alumina additive on the properties of autoclaved gas-silicate. The relationship between the physical and mechanical properties of gas-silicate and the type and quantity of fine filler was established. Results showed that the average density of cellular concrete decreased while strength characteristics were maintained, attributed to a more uniform granulometric composition of activated components. The high specific surface area of the composite binder enhanced hydration quality. Scaling these results could contribute to solving environmental challenges by reducing waste and enhancing material performance.

Keywords: Gas-silicate concrete, Ash and slag wastes, Composite binder, Activation technology, Additives, Characterization improvement.

1. INTRODUCTION

Waste from the combustion of Ekibastuz coals amounts to many millions of tonnes annually. Fly ash, which is captured by electrostatic precipitators, is a popular object of research in the environmental direction. Many research works are devoted to fly ash in the countries of the Commonwealth of Independent States (CIS) and abroad [1]. This is connected to the fact that huge masses of waste from thermal power plants accumulate near megacities. Expensive suburban land is occupied by ash dumps with a tendency to increase. At the same time, the market value of nearby land and buildings is significantly reduced [2]. Ash and slag dumps are expensive to maintain. The costs of wet transportation of waste to the dump account for more than ten percent of the production cost of products of thermal power plants (TPP) - electricity and heat.

In world practice, many different compositions and technologies for obtaining composite binders and concrete based on ashes from thermal power plants and other secondary resources have been developed. Still, their qualitative, ecological, and economic indicators, as well as the energy intensity of production, do not meet modern requirements. Experimental and theoretical works on the creation of new binding agents from industrial wastes with the use of mills of superfine grinding of the new generation are perspectives in the solution of scientific and practical problems [3-5].

When investigating the possibility of utilizing inactive fly ash in road soil concrete, it was found that the optimum content of binder and fly ash in soil concrete was 8 and 10%, respectively. After mechanical activation in the vibratory abrasion machine, the inactive fly ash acquired increased reactivity. By mechanical activation, the specific surface area of fly ash can be improved about twofold. At the same time, dehydration and carbonization, as well as the substitution of silicon for aluminum in silicon-oxygen compounds, take place [6,7]. The increase in the content of the crystalline carbonate phase is the reason for the increase in the strength of the soil concrete. The introduction of ground fly ash into the composition of the soil concrete improves physical and mechanical characteristics. At the same time, the maximum strength grade reaches M100. This indicates the possibility of using inactive fly ash in road construction [8-10].

The use of fly ash as a substitute for part of the binder in concrete and cement mortars significantly reduces the cost of their production. Improved air exchange due to the porous structure of waste grains increases the corrosion resistance of reinforced concrete in aggressive environments.

This structure provides a good basis for the application of interior finishes in residential areas. However, thermal energy waste becomes hydrated or inert during long-term storage in hydraulic dumps. This fact prevents the wide use of waste heat energy in the production of construction materials. Without additional technological treatment, ash and slag cannot be effectively utilized. Another direction of activation of physicochemical and technological properties of ash and slag wastes is mechano-chemical treatment of their constituent components [11,12].

Grinding activation is an accessible tool for the transformation of internal structure and improvement of properties of materials, that are in the landfills of long-term storage. It is based on the formation of a new surface under the action of mechanical forces. This process leads to a change in the reactivity of solids .

Despite the achievement of unique properties, the production of highly dispersed mechanically activated cement compositions is hampered by several reasons. The first is the high energy consumption for mechanochemical activation in conventional mills. The second is the loss of the acquired activity during storage and transport. The third reason is technological difficulties in obtaining highly homogeneous mixtures.

Grinding and mechanical activation of cement compositions in a liquid medium are more effective by several indicators. However, this technology is not widely used due to the impossibility of obtaining highly dispersed mixtures on standard equipment. In addition, the processes that occur during the activation of cement compositions in a liquid medium have not been sufficiently studied [13,14].

Increasing the efficiency of mechanochemical activation of cement compositions is associated with the expediency of intensive physical and chemical impact. The purpose of such an impact is to change the initial state of the system in micro-volumes. The result will be an increase in its homogeneity and optimization of the rate and mechanism of hydrate phase formation in the presence of water. Such a structure is more resistant to recrystallization. Its ability to synthesize numerous strong contacts per unit volume increases. The paper shows the significance of the study and the materials and techniques used. The results of the study of properties of gas-silicate concrete showed the prospects of their production on the basis of nanoactivated components.

2. RESEARCH SIGNIFICANCE

Utilizing ash and slag waste in silicate concrete production requires prior processing. Developing cellular concrete compositions with fly ash and bottom ash enables gas-silicate production with minimal cement. The objectives of the research are: to obtain activated binders, development compositions, and study of properties of gas silicates with the use of aluminous additive.

The novelty of the research lies in the development of the theory of regulation of the properties of nanoactivated silicate systems when introducing an alumina-containing additive into their composition, enhancing the physical and technical properties of gas silicates from composite binders.

3. MATERIALS AND METHODS OF RESEARCH

To achieve the objectives of the scientific study, an analysis was conducted on the elemental composition of the ash produced by the Ekibastuz thermal power plant. The ash was collected from the ash removal devices over the year.

The observation and comparison methods revealed a high degree of heterogeneity in composition and structure over time. The properties of the ash and the compositions of the bottom ash were investigated at different processing modes in the superfine grinding mill. The physical and mechanical properties of the ash and slag silicates were determined.

To carry out the study, the following were used:

- Portland Cement LLP “PO Kokshe-Cement” CEM 1 32.5 N according to GOST 31108-2016;
- calcium lime of the third grade of Keregetas deposit ST RK 9179-07 “Construction lime. Technical conditions”;
- quartz sand Limited Liability Partnership (LLP) Sputnik GPS and Karasorskoye fields;
- slag from Karaganda Metallurgical Plant;
- The ash in question is derived from a dry selection of the Ekibastuz power plant, which has been evaluated by the GOST 25592-91 standard. This standard pertains to "Mixtures of ash and slag from thermal power plants for concrete".

Table 1 Chemical composition of ash at Ekibastuz GRES-2

Oxides content, %												
SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	FeO	SO_3	P_2O_5	MnO	ignition losses
65.0	3.50	28.0	1.00	0.40	0.56	0.26	0.20	0.70	0.60	0.40	0.30	2.30

The calculated specific surface area of the ash is 3066 cm²/g, the bulk density is 830 kg/m³, and the true density is 2250 kg/m³. The chemical composition of the ash is presented in Table 1.

- aluminum-containing additive with an active aluminum content of 82%. subsequently reduce this figure. The consumption of materials per 1 m³ of gas silicate is presented in Table 2.

The density was determined by ST RK 10180, while the compressive strength was evaluated by GOST 18105-10.

The calculated density of the concrete was established at 700 kg/m³, to the technology employed in the manufacture of samples was the

prevailing technology used for the production of products derived from gas silicate. The molds needed to be heated to a temperature of up to 400°C. Once the molding process was complete, the molds with samples were maintained at atemperature of at least 200°C for a minimum of two hours, until the plastic reached a strength of at least 0.15 kg/cm².

The maximum rate of heating and cooling in the autoclave was 2 degrees per minute.

4. RESULTS AND DISCUSSION

One method of improving the homogeneity of the structure of cellular silicate concrete is through the mechanochemical activation of initial components [15,16]. The composition of the composite binder of the investigated concrete includes ash-and-slag waste and an alumina-containing additive. The presence of these substances results in alterations to the structure of neoplasms, the properties of the composite binder, and the concrete itself. One of the activation methods is mechanochemical treatment by ultrafine grinding. The mechanical grinding of the glassy components of the ash and slag waste results in their destruction. Consequently, new surfaces are formed and the material's reactivity is enhanced. To obtain a high-quality gas silicate, it is essential to ensure that all components possess a high specific surface area and a stable grain composition [17,18].

The sand, slag, and ash were subjected to ultrafine grinding in a vibrating mill for 10, 20, and 30 minutes, respectively. The sieving outcomes after grinding are exhibited in Table 3.

The following methods of producing composite binders are considered:

1. Mixing Portland cement with sand, ash, or slag of natural specific surface area;
2. Grinding of sand, ash, or slag to a specific surface area of 5000 cm²/g;
3. Grinding of sand, ash, or slag in the presence of a complex aluminous additive up to a specific surface area of 5000 cm²/g.

The grinding of sand for 10 and 20 minutes did not result in any notable effects. The modulus of coarseness exhibited a notable decline, from 2.83 to 2.39. Consequently, it is not advisable to utilize this sand for the production of cellular concrete. A grinding time of 30 minutes permitted the attainment of a grain size modulus of 1.59. In this instance, the energy consumption associated with prolonged grinding demonstrated a lack of efficiency in the methodology employed.

The grinding of the slag for 10, 20, and 30 minutes resulted in the production of ground slag with a grain size modulus of 1.87, 1.58, and 0.90, respectively. To obtain a suitable slag for the production of cellular concrete, a grinding time of 30 minutes is sufficient. The efficiency of energy consumption during long grinding of slag can be determined by the results of strength testing of samples and the potential for cement savings.

The initial dimensions of the ash and slag waste are relatively small.

Table 2 Material consumption per 1 m³ of gas silicate

Composition number	Type of filler	Cement		Lime, kg	Sand, kg	Filler		Aluminum additive, kg
		%	kg			%	kg	
1	-	100	250	250	250	-	-	2.2
2	Ash	90	225	250	250	10	25	2.2
3		70	175	250	250	30	75	2.2
4		50	125	250	250	50	125	2.2
5		30	75	250	250	70	175	2.2
6		10	25	250	250	90	225	2.2
2a	Slag	90	225	250	250	10	25	2.2
3a		70	175	250	250	30	75	2.2
4a		50	125	250	250	50	125	2.2
5a		30	75	250	250	70	175	2.2
6a		10	25	250	250	90	225	2.2

This is one of the reasons why ultrafine grinding is a complex process. Furthermore, the composition of these materials includes a considerable quantity of vitrified melted particles.

These particles are formed as a consequence of the oxidation of coal or the melting of metals during the production process. The melting of ash and slag particles results in their hardening. It can be posited that a grinding time of no longer than 20 minutes represents the optimal duration. It is not rational to prolong the grinding process, as the alteration in particle size distribution is minimal, and the associated energy costs can be significant. The objective of grinding concrete components is to produce a material with the highest possible specific surface area. Concurrently, the objective is to minimize energy costs. The process of fine grinding is of critical importance in the mechanoactivation of substances, facilitating the intensification of physical and chemical processes. During the grinding process, the material grains are initially subjected to volumetric deformation, which is then followed by fracture along the defect-weakened cross-sections.

The formation of macro- and microcracks results in the generation of new surfaces. In accordance with the theory proposed by academician Rebinder P.A., the energy expended during the grinding of a solid body is equal to the sum of the work of deformation of the material and the work of formation of new surfaces. The work of grinding is proportional to the volume of the material being crushed and the size of the surfaces that are formed. Consequently, the physical and chemical properties of materials are subject to alteration as a consequence of the application of mechanical forces [19,20].

In the initial phase of the grinding process, coarse grains with low strength are readily crushed. Consequently, there is a notable increase in the specific surface area and a reduction in the coarseness modulus. The presence of a greater number of surface defects in larger metallurgical slags can be used to explain the results obtained.

Subsequently, the capacity of the grains to be ground decreases and becomes constant. An increase in grinding time to 30 minutes results in a significant rise in energy costs.

Table 3 Characteristics of the grain composition of ground sand, slag and ash

Residues on sieves	5	2.5	1.25	0.63	0.315	0.14	≤ 014	Total	Size module
Sand 10 minutes grinding									
Total balances, %	0	6.02	22.59	44.88	71.69	93.98	100	0	2.39
Sand 20 minutes grinding									
Total balances, %	0	1.98	19.14	39.60	74.59	95.38	100	0	2.31
Sand 30 minutes grinding									
Total balances, %	0	0.00	0.00	7.24	57.93	94.14	100	0	1.59
Slag 10 minutes grinding									
Total balances, %	0	0	3	26	69	89	100	0	1.87
Slag 20 minutes grinding									
Total balances, %	0	0	0	14	60	84	100	0	1.58
Slag 30 minutes grinding									
Total balances, %	0	0	0	0	17.7	72.4	100	0	0.90
Ash 10 minutes grinding									
Hole sizes	1	0.5	0.25	0.1	0.08	0.04	0.02	0.01	0.005
Residue on sieves, %	0.2	1.12	7.3	27.13	39.5	12.85	4.7	4.4	2.8
Ash 20 minutes grinding									
Residue on sieves, %	-	-	1.12	10.54	10.34	10.0	25.0	22.5	20.5
Ash 30 minutes grinding									
Residue on sieves, %	-	-	1.0	8.6	20.5	17.4	14.0	13.0	25.5

The mean increase in specific surface area and decrease in coarseness modulus is 40%. An increase in grinding time has the opposite effect on the increase of specific surface area.

The quality indicators of ash and slag wastes can be enhanced through the utilization of diverse surfactants, which facilitate the grinding process and augment the chemical activity of the resulting mixtures [21].

The utilization of activated ash and slag mixtures enabled the fabrication and assessment of gas-silicate samples. The outcomes of the tests on density, strength, and coefficient of structural quality (c.c.c.) are presented in Table 4 and Figures 1,2.

Table 4 Gas-silicate test results

Composition number	Average density, kg/m^3	Ultimate compressive strength, MPa	C.C.Q
1	774	2.85	0.37
2	964	4.34	0.45
3	920	2.95	0.32
4	843	2.36	0.29
5	662	1.29	0.19
6	563	0.53	0.08
2a	994	2.49	0.28
3a	857	1.62	0.19
4a	988	0.79	0.08
5a	698	0.35	0.05
6a	861	0.55	0.07

The addition of activated ash up to 10% was found to result in a 52% increase in the strength of the gas silicate, as demonstrated by the results of the strength tests. An increase in the quantity of activated fly ash up to 30% results in a reduction in the strength of the material to a level comparable to that of the control mix. An increase in the quantity of activated ash beyond a certain point results in a gradual decline in the strength of the concrete. The incorporation of activated slag did not yield any discernible benefits at any dosage of activated slag. It can therefore be concluded that the quantity of activated ash present in the composition of gas silicate should not exceed 30%. This phenomenon can be attributed to the formation of an optimal number of crystallization centers, which increases the contact surface area between cementite grains and finely ground activated ash particles. The particles of ground slag did not exhibit such activity.

The coefficient of structural quality is an extended characteristic. This approach unifies the concepts of strength and density into a single characteristic of concrete. In the case of cellular concrete, the second most important characteristic is that of density. To illustrate, in the case of mix 2, which exhibited a 52% enhancement in strength, the structural quality factor increased by a mere 21%. The enhanced density of gas silicate had a detrimental impact on the performance of ready-mixed concrete. The utilization of activated slag yielded unfavorable outcomes. The incorporation of activated slag resulted in a notable decline in strength and an accompanying increase in density across all samples. The gas silicate mixture is a complex system comprising multiple components. In the study of concrete compositions, it is assumed that they are a variant of a more general category [22,23].

The results and conclusions presented above do not allow for a sufficient consideration of the properties of the gas-silicate mixture, and thus, recommendations on the quality of the compositions cannot be made. It is therefore necessary to consider a wider range of materials when making recommendations regarding the composition of the silicate mixture.

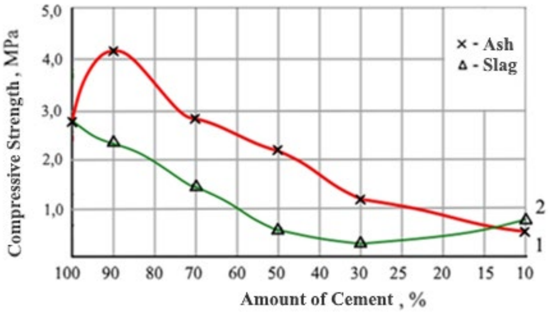

Fig. 1 Dependence of the compressive strength of gas silicate on the amount of cement and type of filler

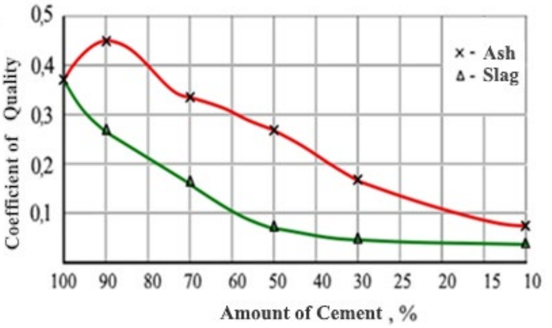

Fig. 2 Dependency c.c.c. gas silicate depending on the amount of cement and type of filler

To this end, the interaction of finely ground fillers with the cement-lime-sand system was subjected to analysis. Figures 3 and 4 illustrate the relationship between strength and structural quality, as a function of the ratio of cement, lime, and sand to activated ash or slag. The incorporation of 20% activated ash into the raw material mix has been observed to enhance the structural quality factor of the resulting gas silicate. This is equivalent to a 30% content of activated ash in the binder. In light of the observed interactions between the various components of the gas silicate, it can be concluded that the addition of 20% activated ash will result in an improvement in the quality indicators. The addition of slag to the compositions did not result in a notable improvement. The utilisation of activated slag in the production of gas silicate necessitates the employment of alternative technological methodologies.

The technical characteristics of gas silicate, when combined with activated components and a complex aluminium-containing additive, remain unimpaired when administered within the optimal dosage limits. The water-cement ratio exerts the greatest influence on strength, followed by the reactivity of the filler and then the granulometric composition of the filler.

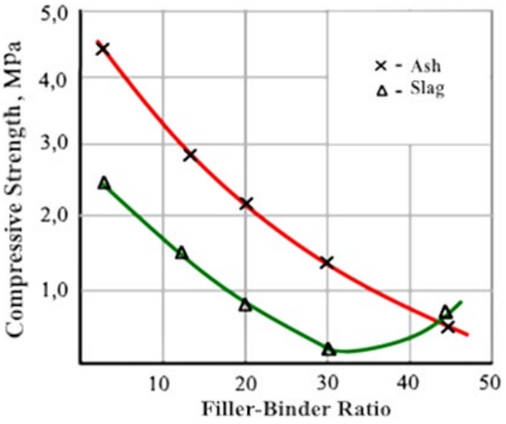

Fig. 3 Dependence of the strength of gas silicate on the type and amount of filler

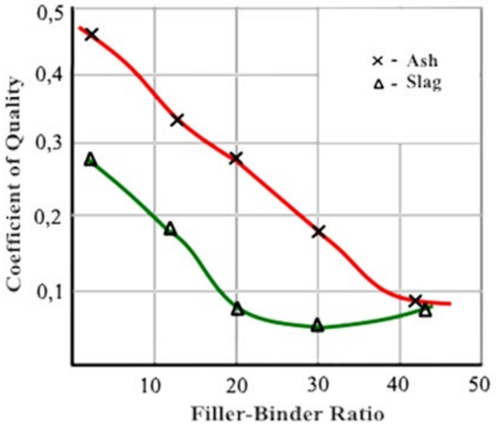

Fig. 4 Dependence of the constructive quality coefficient (c.c.q) of gas silicate on the type and quantity of filler

The incorporation of activated ash into silicate mixtures yields the most favourable performance indicators. The process of fine grinding facilitates an increase in homogeneity and an improvement in the characteristics of ash and slag, which can be used as microfillers in cellular mixtures. The formation of a highly homogeneous structure through mechanical activation facilitates the uniform development of processes throughout the volume of the system. In the system comprising cement, lime, activated components and sand, the formation of the structural framework occurs rapidly following the addition of water. The process of structure formation is comprised of a series of elementary processes. The principal processes are as follows: the adsorption of water molecules on the active centres of the components; the excitation of active centres; the formation of active groups; the hydration of silicate groups; the formation of hydrate nuclei with a high specific surface; and the formation of crystallisation nuclei. A crystallisation nucleus is defined as a small, newly-formed complex comprising a minimum number of units. Such new formations are capable of existing independently. Furthermore, they serve as the nuclei for the formation of a new phase. The strength and other properties of the hardening cement-ash and cement-slag system are contingent upon the type of hydrates that are formed. The activation of ash facilitates the formation of crystallisation centres and enhances the strength of the material. Slag functions as a structure-compacting agent while exhibiting low activity.

The findings demonstrate that it is feasible to produce cellular silicate concretes comprising activated components in the presence of a complex aluminium-containing additive. The optimal concretes are those with the maximum value of the coefficient of structural quality, which is indicative of an optimal ratio between strength and density. In order to achieve the objective of reducing both the density and the consumption of cement while maintaining a minimum level of strength, the addition of ash can reach 30%, while the addition of activated slag should not exceed 10%. It is feasible to substitute a portion of the cement with ash, not exceeding 10%.

The optimal compositions will be those with an ash-binding or slag-binding ratio of no more than 2.25. The structure formation of composite systems was found to be dependent on the kinetics of strength increase. The incorporation of ash into the binder prolongs the induction period of the coagulation structure. The incorporation of a complex aluminium-containing additive facilitates the process of structure formation and enhances the specific surface area. The incorporation of ash into the composite binder results in a reduction in the intensity of heat generation.

The findings of these studies indicated that the use of ash additives in aerated concrete mixtures is feasible, but that the maximum permissible proportion is 20% of the sand weight. The activation of aerated concrete components was not addressed.

The aluminium-containing additive has been observed to reduce the density and thermal conductivity coefficient by 3% for a composition with a cement consumption equal to that of the control composition, and by 12% with a higher cement consumption. The compressive strength of the mixture is observed to decrease by 60% in comparison to the control composition with a low cement consumption and by 20% in comparison to a composition with an increased cement consumption when the additive is introduced. The coefficient of structural quality when an aluminum-containing additive is used increases by 60 and 40%, respectively, with low and increased cement consumption compared to the control composition.

A number of factors affect the gas-forming ability of the mixture. The principal factors influencing the gas-forming ability of a mixture are the initial viscosity, fluidity and temperature of the mixture, the rate of formation of a structure with specific mechanical properties, the dispersion of the components and their quantity, and the chemical composition of the medium. In the event that the mixture fails to attain the requisite load-bearing capacity following the swelling process, it will inevitably settle. In the event that the mixture hardens prior to the conclusion of the gas formation process, the specified density of aerated concrete will not be achieved.

The use of ash from Ekibastuz power plants and slag from the Karaganda Metallurgical Plant in the production of aerated concrete is not recommended, as they are low-active materials. The addition of activating additives is necessary to achieve the desired results. Without such additives, the use of these materials will be unprofitable or impossible due to the fact that the massif cannot be deformed and cut for a long time. The utilization of activated ash and slag waste will result in a reduction of approximately 8% in the cost of cellular silicate concrete, which will lead to savings of almost 80 kg of cement per 1 m^3 of concrete.

5. CONCLUSION

Compositions of gas silicates with activated ash from thermal power plants and slag from metallurgical production were developed. Superfine grinding and complex alumina-containing additives were used for the activation of concrete components. The results of the investigation of the properties of gas silicate concrete made with nano-activated components are presented. It is found that the addition of activated ash instead of a part of cement should not exceed 20%. The addition of activated slag should not exceed 10%. In the total volume of raw components, the amount of activated ash can be up to 10%, slag - up to 5%. Activation of the composite system in the presence of complex aluminous additives allowed us to obtain better results than when using standard materials. Realization of the proposed developments will lead to saving of almost 80 kg of cement per $1m^3$ of concrete and solve environmental problems. The results of the research can be recommended for production. The mechanism of interaction between the components of the activated gas-silicate mixture and the formation of the gas-silicate structure is a subject for further research.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] Nwachukwu M.A., Ronald M., and Feng H. Global capacity, potentials and trends of solid waste research and management, Waste Management & Research. Vol. 35, Issue 9, 2017, pp. 923- 934.

[2] Xin Y., Mohajerani A, Kurmus H., Smith J. V. Possible recycling of waste glass in sustainable fired clay bricks: a review. International Journal of GEOMATE, Vol.20, Issue 78, 2021, pp. 57-64.

[3] Andreola F., Barbieri L., Lancellotti I., Leonelli C., and Manfredini T. Recycling of industrial wastes in ceramic manufacturing: State of the art and glass case studies, Ceramics International. Vol. 42, Issue 12, 2016, pp. 13333-13338.

[4] Panova V., Panov A. Coal Enrichment Waste As Raw Materials for Manufacturing Building Materials. Bulletin of the Siberian State Industrial University, Vol. 2, Issue 12, 2015, pp. 71-75.

[5] Nuguzhinov Z., Tokanov D., Tazhenova G., Rakhimov A., Kurokhtina I. Studying the causes of the open type overland car parking collapse in Nur-Sultan. IOP Conference Series: Materials Science and Engineering, 2020, pp. 953-959.

[6] Vyshar O., Stolboushkin A., Rakhimova G., Stanevich V., Rakhimov M. Study of the properties of overburdened rocks from coal mining: overburden – as a raw material in the production of ceramic bricks. International Journal of GEOMATE, Vol. 25, Issue 107, 2023, pp. 86–94.

[7] Rakhimova G., Slavcheva G., Aisanova M., Rakhimov M., Tkach E. The influence of a complex additive on the strength characteristics

of concrete for road construction. International Journal of GEOMATE. Vol. 25, Issue 110, 2023, pp.243-250.

[8] Bespolitov D., Konovalova N., Dabizha O., Pankov P., Rush E. The influence of mechanical activation of fly ash on the strength of soil concrete based on industrial waste. Ecology and industry of Russia. Vol. 25, 2021, pp. 36-41.

[9] Ezhova A.I. Assessment of technogenic raw materials in the Russian Federation (Solid minerals). Mining Science and Technology, Vol. 4, 2016, pp. 62-72.

[10] Safarov K. B., Stepanova V. F. Regulating the reactivity of aggregates and increasing the sulfate resistance of concrete through the combined use of low-calcium fly ash and highly active metakaolin. Construction Materials. Vol. 5, 2016, pp.70-73.

[11] Endzhievskaya I. G., Vasilovskaya N. G., Dubrovskaya O. G., Baranova G. P., Chudaeva A. A. The influence of mechanical activation on the stabilization of the properties of fly ash. Siberian Federal University, Krasnoyarsk, Vol. 3, 2018, pp. 53-70.

[12] Girnis S., Ukrainets V., Stanevich V., Gorshkova L. Akhmetova A. The transport load influence on a reinforced two- layered tunnel lining. International Journal of GEOMATE. Vol.26, Issue 117, 2024, pp.27-34.

[13] Dvorkin L., Dvorkin O. Calculation forecasting of properties and design of concrete compositions.Infra-Engineering, 2016. pp.1-385.

[14] Tkach E., Serova R., Stasilovich E, Imanov Y., Bogoyavlenskaya T. and Khan M. Modified aerated concrete based on man-made waste. International Journal of GEOMATE. Vol.23, Issue 97, 2022, pp.131-138.

[15] Rakhimov M.A., Rakhimova G.M., Suleimbekova Z.A. Modification of concrete railway sleepers and assessment of its bearing capacity. International Journal of GEOMATE. Vol.20, Issue 77, 2021, pp. 40-48.

[16] Amran M., Fediuk R., Vatin N., Huei Lee Y., Murali G., Ozbakkaloglu T., Klyuev S., Alabduljabber H. Fibre-Reinforced Foamed Concretes: A Review. Materials. Vol. 13, Issue 19, 2020, pp. 43-53.

[17] Nuguzhinov Z., Tokanov D., Tazhenova G., Rakhimov A., Kurokhtina I. Studying the causes of the open type overland car parking collapse in Nur-Sultan. IOP Conference Series: Materials Science and Engineering, 2020, pp. 953-959.

[18] Gorshkov A.S., Vatin N.I. Properties of the wall structures made of autoclaved cellular. International Journal of GEOMATE. Vol. 23, Issue 97, 2022, pp.131-138.

[19] Tkach E., Rakhimov A.Porous fillers for light concrete from technogenic raw materials. IOP Conference Series: Materials Science and Engineering. Vol. 365, Issue 3, 2018, pp. 032014.

[20] Baidzhanov D., Nuguzhinov Z., Fedorchenko V., Kropachev P., Rakhimov A., Divak L. Thermal insulation material based on local technogenic raw material. Glass and Ceramics, Vol. 73(11-12), 2017, pp. 427-430.

[21] Mashkin N., Esirkepova A., Sherov K., Rakhimova G., Zharkevich O., Mussayev M. Activation of Cement Binderin Heavy Concrete Technology. Material and Mechanical Engineering Technology, Vol. 3, 2020, pp. 9–12.

[22] Rakhimova G., Zhangabay N., Samoilova T., Rakhimov M., Kropachev P., Stanevich V. Computational Research of the Efficiency of Using a Three-Layer Panel Made of Highly Porous Polystyrene Concrete. Journal: Materials, 2024, Vol.17, Issue 4133, pp. 2–19.

[23] Akishev K., Tleulessov A., Aryngazin K., Bulyga L., Stanevich V. The use of simulation modeling in calculating the productivity of the technological system for the production of building products with fillers from man-made waste. NEWS of the National Academy of Sciences of the Republic of Kazakhstan Series of geology and technical sciences, Vol. 4, Issue 466, 2024, pp. 22–32.