Architectural Studies
International Journal about Architecture

Volume 10, No. 2

UDC 666.9
DOI: 10.56318/as/2.2024.162

Sarsenbek Montayev*
Doctor of Architecture, Director of the Industrial Technology Institute
West Kazakhstan Agricultural University named after Zhangir khan
090009, 51 Zhangir khan Str., Uralsk, Republic of Kazakhstan
https://orcid.org/0009-0001-7045-9074

Karzhaubai Dosov
Senior Lecturer
West Kazakhstan Agricultural University named after Zhangir khan
090009, 51 Zhangir khan Str., Uralsk, Republic of Kazakhstan
https://orcid.org/0009-0001-4771-1008

Nurgul Adilova
PhD in Architecture, Associate Professor
West Kazakhstan Agricultural University named after Zhangir khan
090009, 51 Zhangir khan Str., Uralsk, Republic of Kazakhstan
https://orcid.org/0009-0009-1616-3000

Ainur Montayeva
Head of the Department of Scientific Research Coordination
Korkyt ata Kyzylorda University
120014, 29A Aiteke bi Str., Kyzylorda, Republic of Kazakhstan
https://orcid.org/0000-0001-9536-3442

Maira Almagambetova
PhD in Engineering, Associate Professor
West Kazakhstan Agricultural University named after Zhangir khan
090009, 51 Zhangir khan Str., Uralsk, Republic of Kazakhstan
https://orcid.org/0009-0001-6397-8132

Technology of granulated ceramic aggregate for concrete based on clay of Atyrau deposit of Western Kazakhstan

Abstract. The purpose of this study was to investigate the technology of granular ceramic aggregate based on clay of Atyrau deposit, with a focus on improving the mechanical and thermal properties of concrete to achieve best efficiency and sustainability in construction. The methods employed in this study included chemical analysis, X-ray phase analysis, electron microscopy. Using these methods, the physical-mechanical and chemical-mineralogical characteristics of the ceramic aggregate were determined. The study presents solutions to the problem of providing the construction industry of the West Kazakhstan region. It highlighted the key characteristics of the material, its structural features, and its effect on concrete properties. The study presented the errors occurring during the application of granular ceramic aggregate technology and identified the reasons for their occurrence. The functioning of the technology was analysed,

Suggested Citation:
Montayev, S., Dosov, K., Adilova, N., Montayeva, A., & Almagambetova, M. (2024). Technology of granulated ceramic aggregate for concrete based on clay of Atyrau deposit of Western Kazakhstan. *Architectural Studies*, 10(2), 162-171. doi: 10.56318/as/2.2024.162.

Journal homepage: https://arch-studies.com.ua/en
Architectural Studies, 10(2), 162-171
Received: 25.07.2024 Revised: 15.11.2024 Accepted: 18.12.2024

*Corresponding author

which is critical for determining its efficiency, its potential for development, and for identifying possible improvements in the operation of the respective industries. The evaluation of the performance of concrete with granular ceramic aggregate, the rationale for the use of this material, the limitations in use, and the impact of these limitations on the quality of the final product were discussed. The study proposed recommendations aimed at optimising the application process of granular ceramic aggregate, improving the reliability of concrete, and considering a range of factors affecting production and operational aspects

Keywords: construction; natural resources; exploitation; component; engineering system

INTRODUCTION

The study of granular ceramic aggregate technology for clay-based concrete represents an essential stage in the development of the construction industry. This is conditioned by the potential improvement in the mechanical properties of concrete. The use of clay as an aggregate brings environmental sustainability, reducing dependence on artificial materials. Alumina (a key component of clay) may be available and cheaper than conventional building materials. The unique properties of clay, such as good thermal and acoustic insulation, offer opportunities for creating energy efficient buildings and improving living conditions. Research into this subject can lead to the development of new materials and construction methods, contributing to the continuous improvement of the industry.

The problematic of researching the technology of granular ceramic aggregate for clay-based concrete lies in the need to determine the best method of creation and implementation of this material in the construction sphere (Kolesnikova *et al*., 2023). Researchers face challenges such as determining suitable physico-chemical characteristics of clay, developing an efficient granulation technology, analysing the effect of aggregate on concrete properties, and assessing the economic and environmental feasibility of the technology.

According to S. Montayev & M. Ryskaliev (2020), ceramic porous aggregates, which are natural or artificial porous stone materials with a bulk density not exceeding 1,200 kg/m^3, find application in modern construction in the creation of lightweight concrete. These lightweight aggregates are usually produced by thermal treatment of the clay raw material, followed by screening or crushing and subsequent grading. Ceramic materials have thus been successfully introduced into concrete production, occupying their specialised niche (Kutsenko & Kutsenko, 2022). This study did not investigate the effect of different heat treatment temperatures of clay raw materials on the properties of ceramic porous aggregates. S. Montayev & D. Majit (2021) propose a simplified technology to produce ceramic aggregate with low bulk density. The essence of the method is thermal treatment of clay shale at a temperature impact of 700-800°C,which leads to cracking of grains and reduction of bulk density by 1.5 times compared to conventional methods. This study did not investigate the effect of changes in the structure of ceramic aggregate on its mechanical properties.

N. Bekkaliev *et al*. (2021) focus on the problems associated with the shortage and excessive cost of crushed stone used in construction, especially in reinforced concrete structures and road construction. To solve this problem, it is proposed to use road construction expanded clay aggregate, a material based on clay processing, which can replace crushed stone and be used as a thermal insulation material (Tassybekov *et al*., 2020). The authors also propose to integrate industrial wastes such as metallurgical slags and ashes from combined heat and power plants (CHP) into the production of road construction expanded clay aggregate. This study did not investigate the effect of proportions of industrial wastes such as ash from CHP on the physical and mechanical properties of road construction expanded clay aggregate.

Ye. Ryltsev (2017) presented a method of production of ceramic porous aggregate using oil sludge addition to montmorillonite clay. This not only improves the quality of the aggregate, but also contributes to the utilisation of waste and the replenishment of the raw material base with new materials (Khrystych, 2023). The economic benefit of this method is the reduction of raw material and production process costs (Astakhova & Astakhov, 2024). This study did not investigate in detail the effect of oil sludge additive on the environmental resistance and environmental sustainability of ceramic aggregate. A. Hotovkin (2023) conducted experiments to create expanded clay by introducing loess-like loams into bentonite clays. The results demonstrate the transition of loams from non-swelling to medium-swelling clays. Increasing the content of bentonite clay from 20 to 50% was accompanied by a decrease in the average density of samples and an increase in granule strength by 2.5-3 times. This study did not analyse the effect of different proportions of components on the structural features of expanded clay, such as its porosity and granule shape.

The purpose of this study was to comprehensively analyse the influence of a range of factors such as heat treatment temperature, structure changes, industrial waste proportions, on the properties of ceramic aggregate, considering its physical and mechanical characteristics. The objectives of this study were to analyse the physical and chemical properties of clay from the above-mentioned deposit, including mineral composition and particle structure, to develop and optimise granulation technology for the production of ceramic aggregate, and to evaluate the effect of aggregate on the mechanical properties of concrete and its stability.

MATERIALS AND METHODS

The study of granular ceramic aggregate technology was conducted using various methods. Functional method in the study of this topic contributed to a more profound understanding of the properties of clay Atyrau deposit and optimise its use in the technology of granular ceramic aggregate for concrete. The synthesis method helped to form the best material composition and improve its properties to increase the strength and stability of concretes; to highlight key findings, draw general conclusions, and generalise the findings. The systematisation method helped in organising the data, identifying relationships and creating a unified model for better learning and optimising the material. The comparison method in the study helped in identifying the most effective technology options, determining the best parameters and selecting the best solutions to create a quality and competitive material. The chemical analysis method helped to determine the composition of the raw materials, identify interactions between components, and control the quality of the material produced, thus improving production efficiency and ensuring compliance with standards. The method of X-ray phase analysis in the study contributed to the identification of crystalline phases in the material, determination of structural characteristics and phase composition, which is key to understanding the formation of the material structure and its properties. The electron microscopy method facilitated visual analysis of the microstructure of the material, revealing its morphological features, particle sizes, and distribution of components, and provided a detailed understanding of the internal structure of the aggregate.

The study of granular ceramic aggregate for clay-based concrete was carried out in Zhangir Khan West Kazakhstan Agricultural University. Loam from Atyrau deposit was selected as the main raw material, while ash from Ekibastuz State District Power Plant (SDPP) was used as a modifying component (Fig. 1).

Figure 1. Ekibastuz State District Power Plant
Source: compiled by the authors

Clay samples were taken directly from the quarry and standards including the State Standard of the Republic of Kazakhstan (ST RK) No. 992-96 (1996) were used to evaluate their properties in laboratory conditions. After transporting the ash and clay samples, analyses were carried out to determine their physical and mechanical properties and chemical and mineralogical composition. Firstly, the raw materials were dried in an electric desiccator at 70-80°C until a final moisture content of 5-7% was achieved. The dried clay components were then pulverised in a laboratory ball mill until they passed through a sieve with 1 mm aperture size. The obtained powdered raw materials were dosed using electronic scales and transferred into a metal spherical bowl for further mixing with water. Initially, the raw materials were mixed in a spherical bowl until a homogeneous texture was obtained. Then water was added to the obtained mixture in the volume of 20-28% of the weight of dry material. After the introduction of water, the raw material mixture was subjected to stirring until a homogeneous ceramic mass was obtained. This mass was used to produce pellets of different sizes: 5-10 mm, 10-20 mm, 20-40 mm. The formed pellets were then subjected to drying in a desiccator at 70-80°C until constant weight was achieved. After drying, the pellets underwent a firing process in a rotary kiln at 1,000°C. After firing, the pellets were tested for physical and mechanical properties. The samples obtained after firing were thoroughly calcined granules coloured light red.

These studies were carried out to assess the suitability of raw materials for the production of ceramic aggregate (expanded clay aggregate for road construction) and ceramic paving stones. X-ray phase analysis was carried out on a DRON-3 diffractometer using SiCa radiation in the angle range of 80-640, with a method sensitivity of 1-2%. Clay powders passed through a 0.315 sieve were subjected to X-ray phase analysis. Chemical and mineralogical composition of the raw components under study was determined using scanning electron microscope JSM-6390LV with energy-dispersive microanalysis system, X'Pert PRO MPD X-ray diffractometer and inductively coupled plasma mass spectrometer ICP-MS Agilent 7500cx from JEOL, Japan.

The methods employed made it possible to determine the physical and mechanical characteristics, chemical composition and structure of the materials, which is important for assessing their suitability in the technology of production of ceramic materials. This comprehensive study has contributed to a better understanding of the properties of the raw material components and the optimisation of the technological processes in the production of granular ceramic aggregate.

RESULTS

To provide high quality building materials and improve the performance of concrete mixtures, clay-based granular ceramic aggregate technology is being actively developed. This innovative process involves the use of specially treated clay as the main component to create granules that are subsequently incorporated into concrete (Moreno-Maroto *et al.*, 2023).

The study of clay of Atyrau deposit revealed a range of characteristics that determine its properties. Chizhsky drying sensitivity coefficient (Cd): the estimation of this parameter is within 63-66. The drying sensitivity coefficient is an index reflecting the change in the volume of clay material during drying and allowing to judge its plasticity and moulding ability (Bandura *et al.*, 2024). These studies indicate a plasticity number of 10-11. The plasticity number is a measure of the plasticity of clay and is defined as the difference between the yield strength and the compressive strength (Lotero *et al.*, 2021; Shumakov *et al.*, 2024). The range of average clay density values is 1,210-1,240 kg/m^3. Average density is a measure of the mass of clay material in a unit volume (Ghonaim & Morsy, 2023). Chemical and mineralogical composition: clay of Atyrau deposit differs by absence of montmorillonite component. Instead, mixed-layer formations with hydrous mica and kaolinite are present. This indicates the composition of the clay and its mineral composition (Mahmoodi *et al.*, 2023). Different ones have been found in clay, each characterised by its lattice parameters (d/n) (Table 1).

Table 1. Lattice parameters of crystalline phases of Atyrau deposit

Quartz	Feldspar	Calcite	Hematite
d/n = 4.23·10^{-10} m	d/n = 3.18·10^{-10} m	d/n = 3.02·10^{-10} m	d/n = 1.839·10^{-10} m
d/n = 3.34·10^{-10} m		d/n = 2.018·10^{-10} m	d/n = 1.686·10^{-10} m
d/n = 1.974·10^{-10} m	d/n = 2.286·10^{-10} m	d/n = 1.912·10^{-10} m	d/n = 1.590·10^{-10} m
d/n = 1.813·10^{-10} m			
d/n = 1.538·10^{-10} m			

Source: B. Kanagaraj *et al*. (2023)

These data provide information on the structure and composition of the crystalline components of clay, which can be vital for understanding its properties and potential applications in various fields. The Atyrau loam data include high-resolution images of the clay microstructure (Fig. 2), showing particle morphology, structural features, and particle sizes. The clay of the sample under study is characterised by a certain chemical composition (Table 2).

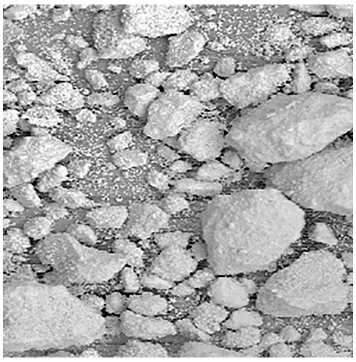

Figure 2. Scanning electron microscopy image of Atyrau loam

Source: compiled by the authors

Table 2. Weight percentages of the elements of the clay sample under study

Element	%
oxygen (O)	52.79
sodium (Na)	0.96
magnesium (Mg)	2.15
aluminium (Al)	7.58
silicon (Si)	18.62
sulphur (S)	0.23
chlorine (Cl)	0.64
potassium (K)	1.92
calcium (Ca)	9.84
titanium (Ti)	0.28
iron (Fe)	5

Source: compiled by the authors

These data provide information on the chemical composition of clay, which is a key aspect when investigating its properties and possible applications in various fields including construction, ceramics, and other industries. As a result of scientific and experimental studies, the main physical and mechanical characteristics of ash were determined. The particle size analysis of ashes shows the content of different fractions depending on the particle size. Particles larger than 0.25 mm represent 5.98%, while particles within 0.05-0.01 mm are represented by a fraction of 43.07%. The specific surface area of ash, a significant parameter, indicates the surface of its particles and ranges within 3,200-3,700 g/cm². The true density of ash, which reflects its mass per unit volume, is within 1.75-1.84 g/cm³. Bulk density, which is the mass of ash per unit volume when bulked, ranges within 675-740 kg/m³. The data on the chemical composition of the ash (Table 3), which includes significant amounts of silica, aluminium oxide, calcium, are essential for determining the characteristics of the ash, its properties, and possible applications such as construction, cement, or other building materials.

Table 3. Chemical composition of ashes obtained from Ekibastuz SDPP

Name of raw material	Oxide content, wt. %												
	SiO_2	Al_2O_3	TiO_2	CaO	MgO	Fe_2O_3	P_2O_5	F	SO_3	CO_2	Na_2O	K_2O	para
Ekibastuz SDPP ash	57.7	24.5	-	1.1	1	4.1	-	-	0.13	-	1.57	-	8.7

Source: compiled by the authors

Each of the chemical elements in the composition of Ekibastuz SDPP ash can influence the production technology of granular ceramic aggregate for clay-based concrete (Table 4).

Table 4. Influence of elements on material properties

Element	Influence
SiO_2 (silica)	Affects strength and stability. Supports the formation of strong structures in ceramics.
Al_2O_3 (aluminium oxide)	Takes part in the formation of crystal structures, affecting mechanical properties. May also affect colour and thermal stability.
CaO (calcium oxide)	Can serve as a binder and improve the properties of ceramic material. Affects strength and stability.
MgO (magnesium oxide)	Affects mechanical properties and thermal stability. Can be used to regulate rheological characteristics.
Fe_2O_3 (iron oxide)	May affect the colour range and structure of the material. A small amount can be positive for mechanical properties.
Na_2O and K_2O (sodium and potassium oxides)	Affect the chemical and physical properties of clay, can activate the ash binder.
P_2O_5 (phosphorus oxide), SO_3 (sulphur oxide), F (fluorine)	May affect glass transition properties and improve material strength.
CO_2 (carbon dioxide)	Affects carbonisation characteristics, which may be essential in the firing process.

Source: compiled by the authors

These elements can be adjusted in the granular ceramic aggregate production technology to achieve best properties for clay-based concretes (Lu *et al.*, 2023). The research area related to the development of ceramic composition for the creation of ceramic aggregate (expanded clay aggregate for road construction) and ceramic paving stones is defined by the maximum permissible concentrations of the components expressed in per cent by mass. In this area of research, the concentration limit ranges were established as follows: loam from Atyrau deposit – from 70 to 90%, and Ekibastuz SDPP ash – from 10 to 30%. Three different ceramic compositions were considered and each of them is characterised by certain percentages of raw materials (Table 5).

Table 5. Characteristics of ceramic compositions

No. of structure	Bulk density, kg/m³	Compressive strength, MPa	Water absorption, %	Heat transfer coefficient, W/mK
1	1,230	8.7	26.4	0.41
2	970	9.3	31.1	0.28
3	860	12.8	34.4	0.21

Notes: firing temperature – 1,000°C

Source: compiled by the authors

During the analysis of changes in physical and mechanical properties of experimental samples depending on the composition of raw materials the following regularities were revealed: introduction of ash from Ekibastuz SDPP within 10-30% leads to an increase in the strength characteristics of samples of expanded clay aggregate for road construction. When fired at 1,000°C, an increase in strength of up to 12.8 MPa is noted. While the average density of the samples decreases, ranging within 860-1,230 kg/m^3. These results of scientific and experimental studies also indicate the acceleration of sintering and crystallisation processes in ceramic masses with the addition of ash from Ekibastuz SDPP (Cantero *et al.*, 2021). From the results of X-ray phase analysis and electron microscopic analysis it follows that the samples contain the following crystalline phases: quartz, needle-shaped crystals of mullite, as well as melted grains of feldspar and hematite. There is an increase in the glassy phase content due to partial melting of clay minerals. The formation of crystalline and glassy phases at 1,000°C favours the formation of porous and robust microstructure of pellet samples. The change in the average density values of the samples is associated with the formation of porous structure due to the burnout of coal residues present in the ash. This conclusion is confirmed by analysing the microstructure of pellet samples made both without ash addition and with ash addition up to 30%. Samples produced without the addition of ash have a dense structure with small micropores. Whereas the pellet samples with ash addition up to 30% exhibit a characteristic complex porous structure due to sintering. Based on the obtained findings, the development of the technological scheme of production of expanded clay aggregate for road construction based on clay rock processing with the use of corrective additives involves a detailed investigation of technological stages (Table 6).

Table 6. Technological stages of ceramic production

Stage	Description
Extraction and preparation	Search and study of clay rock deposits; assessment of clay raw material quality; laboratory analyses; extraction using mechanical or hydraulic methods; transport of clay raw material to the production site.
Sorting and classification	Mechanical sorting and removal of impurities; classification of clay raw materials by particle size.
Addition of correcting agents	Adding corrective additives to the clay mass to correct chemical composition and improve properties; fine-grained additives to improve the flowability of the mixture.
Mixing and moisturising	Mixing of clay mass with additives in special agitators; moistening of the mixture to achieve optimum consistency.
Moulding	Pressing or extrusion of the mixture to create moulded products (slabs, tiles).
Drying	Pre-drying of formed products at controlled temperature and humidity.
Roasting	Subjecting products to firing in furnaces with a certain temperature and time regime to give strength and resistance to external influences.
Glazing (as required)	Application of glaze on the surface of products to improve decorative and protective characteristics; additional firing step to fix the glaze.
Quality control	Conducting tests for strength, water absorption, geometric dimensions, and other characteristics; rejecting products that do not meet standards.
Packaging and storage	Packaging of finished products according to customer requirements; storage in warehousing conditions.
Shipment	Organisation of transportation and shipment of expanded clay aggregate for road construction to customers or construction sites.
Environmental measures	Implementation of waste recycling and reuse system; compliance with environmental protection standards.

Source: compiled by the authors

It is vital to emphasise that the specific processes and parameters will depend on the specifications of the clay raw material, the requirements of the expanded clay and the corrective additives used. In addition, local standards and regulations should be considered when designing the process flow diagram.

DISCUSSION

As a result of the study of clay from the Atyrau deposit in Western Kazakhstan, it was found that these materials are suitable to produce granular sintered ceramic aggregate for concrete. The use of large tonnage secondary resources such as Ekibastuz SDPP ash improves the physical, mechanical, and technological properties of ceramic aggregates. X-ray diffraction and electron microscopic analyses showed the presence of crystalline phases including quartz, mullite, feldspar, and hematite, and an increase in glass phase content when the clay minerals were melted at 1,000°C. This favours the development of a porous and durable microstructure of the granules. The use of Ekibastuz SDPP ash in the ceramic mass also favourably affects the thermal conductivity of the sintered ceramic material, which can increase energy efficiency in the construction of buildings and structures.

N.T. Sithole & T. Mashifana (2020) analysed the crystal phases of clay samples using X-ray diffraction. X-ray microanalysers were used to determine the lattice parameters of quartz, feldspar, calcite, and hematite. The findings of the researchers were as follows: quartz – $d/n = 4.05 \cdot 10^{-10}$ m, feldspar – $d/n = 3.42 \cdot 10^{-10}$ m, calcite – $d/n = 3.10 \cdot 10^{-10}$ m, hematite – $d/n = 1.75 \cdot 10^{-10}$ m. Lattice parameters of crystalline phases of clay from the study of N.T. Sithole & T. Mashifana (2020) and Atyrau deposits have differences. Quartz and calcite have larger lattice parameters compared to clay from the Atyrau deposit, while feldspar and hematite have finer lattice parameters. These differences may indicate different formation conditions and history of these clays, which requires further geological investigation to fully understand their origin and properties. Additional studies may include analyses of impurities, sample formation conditions, and the effect of temperature and pressure on lattice parameters.

G. Bumanis *et al*. (2022) investigated the chemical composition of oil shale, because its strength makes it an ideal material for wall cladding, flooring, and other building elements. The researchers provided weight percentages of the following elements: oxygen (O) – 48.2%, sodium (Na) – 1.15%, magnesium (Mg) – 2.8%, aluminium (Al) – 6.4%, silicon (Si) – 22.1%, sulphur (S) – 1.05%, chlorine (Cl) – 0.75%, potassium (K) – 1.5%, calcium (Ca) – 10.2%, titanium (Ti) – 0.4%, iron (Fe) – 6.55%. Slate has a higher silicon content, which may have a positive effect on its hardness and resistance to high temperatures (Kruglov *et al*., 2023). On the other hand, clay is distinguished by its higher aluminium content, which may give it increased ductility and ability to form ceramic products. The high iron content of oil shale can give it a distinctive colour and affect its strength properties (Nguyen, 2023; Nenastina *et al*., 2024). Apart from chemical analysis, studies may include physical properties (ductility, hardness), thermal properties (heat capacity), structural studies (X-ray diffraction analysis), mechanical properties (strength), environmental aspects (environmental stability) and technological capabilities (processing processes, compatibility with other materials).

L. Jones & R. Urbano Gutiérrez (2023) investigated the properties of granite, as it is widely used for facing facades of buildings, laying tiles, creating countertops, as well as for the construction of bridges, roads, and other infrastructural objects due to its strength, resistance to wear and tear, and aesthetic appearance. The researchers performed a chemical analysis which showed the following results: oxygen (O) – 60.32%, sodium (Na) – 3.1%, magnesium (Mg) – 0.78%, aluminium (Al) – 10.15%, silicon (Si) – 20.85%, sulphur (S) – 0.23%, chlorine (Cl) – 0.45%, potassium (K) – 2.6%, calcium (Ca) – 1.92%, titanium (Ti) – 0.4%, iron (Fe) – 2.3%. Both granite and clay samples contain oxygen (O) and silicon (Si) in appreciable amounts. The presence of aluminium (Al) in both samples, but in different concentrations, which may affect their mechanical properties. Granite contains a high percentage of oxygen and aluminium, which is inherent in granitic rocks that are often used in construction (Linchenko *et al*., 2022). Clay has higher iron (Fe) and calcium (Ca) content, which makes it more suitable for ceramic industry (Soralump *et al*., 2023). Additionally, the geological origin, mineralogical composition, moisture absorption, electrical properties, biological effects, development of new compositions and evaluation of the economic viability of clay and granite can be investigated.

N.P. Martins *et al*. (2021) conducted a study on sedimentary clays. The particle size analysis shows that particles larger than 0.25 mm account for 8.50% and particles within 0.05-0.01 mm account for 38.20%. The specific surface area of clay ranges within 3,000-3,500 g/cm^2. The true density ranges within 2-2.2 g/cm^3 and the bulk density varies from 800 to 900 kg/m^3. Comparative analysis with ash results shows that clay has higher percentage of coarse particles (more than 0.25 mm) and less percentage of particles within 0.05-0.01 mm as compared to ash. The specific surface area of clay is also slightly less than that of ash. The true and bulk densities of clay exceed the corresponding values for ash. J. Migunthanna *et al*. (2022) investigated the chemical composition of ash obtained from coal fired power plant, because it can be effectively used as an additive for building materials which helps in improving the mechanical and thermal properties such as strength and stability. The results are presented as weight percentages of the following elements: SiO_2 – 62%, Al_2O_3 – 20.2%, TiO_2 – 1.5%, CaO – 0.8%, MgO – 0.9%, Fe_2O_3 – 5.5%, P_2O_5 – 0.2%, F – 0.05%, SO_3 – 0.3%, CO_2 – 2.1%, Na_2O – 1.1%, K_2O – 4%. Comparative analysis of chemical composition of ash obtained from Ekibastuz SDPP and ash from coal-fired power plant (CFPP) revealed the following differences and similarities. Both sources have high SiO_2 content, indicating a considerable presence of silicon in both ashes. CaO content is similar in both compositions, while MgO, Na_2O, and K_2O contents are almost absent. While Ekibastuz SDPP ash contains a higher percentage of Al_2O_3, CFPP ash has a higher Fe_2O_3 content. It is also noted that TiO_2, P_2O_5, F, SO_3, and CO_2 are present only in CFPP ash, which may affect its properties and applications. These differences emphasise the need to consider the chemical composition of ash while evaluating its potential use in various industries, especially in the context of construction and material production.

G.S. dos Reis *et al*. (2021) proposed a technological scheme for the production of ceramic tiles from clay and waste sludge from the ceramic industry. Extraction and preparation of raw materials, including prospecting and exploration, quality assessment, and laboratory analyses. Sorting and classification, including removal of impurities and classification of raw materials. Addition of enhancing additives such as hydrogen compounds to improve ductility. Mixing and moistening to achieve best mixture consistency. Moulding through pressing or extrusion. Drying and subsequent firing in special kilns. Glazing and, if necessary, re-firing to fix the glaze. Quality control including tests for strength, water absorption, and geometric dimensions. Customised packaging, storage, and dispatch. Environmental measures, including waste management systems and compliance with environmental standards, are also a significant step.

The discussion of clay-based granular ceramic aggregate revealed the prospects for the use of this material in the construction industry. The discussion helped to emphasise its potential as a functional and effective component for concretes, with certain properties that contribute to improve the mechanical and environmental performance of construction materials. This material not only provides opportunities for sustainable utilisation of natural resources, but also ensures the stability and high strength of the final concrete structures.

CONCLUSIONS

The findings of the study of clay of Atyrau deposit confirm its suitability for use in the technology of granulated ceramic aggregate, which can improve the properties of concrete mixtures. Analysing the characteristics of clay, including its plasticity, crystalline structure and chemical composition, provides important information on potential applications in construction and industry. Ekibastuz SDPP ash was investigated for its fractional composition, specific surface area, true and bulk density.

Chemical analysis highlighted the high content of SiO_2, Al_2O_3, and CaO, which makes this ash a promising component for granular ceramic aggregate in construction. Analysis of physical and mechanical properties of the obtained granules at three different compositions showed a significant influence of the proportions of loam and Ekibastuz SDPP ash on their density, strength, water absorption, and thermal conductivity. As a result of the conducted study of raw materials for granular ceramic aggregate, the main stages of its production were identified. These steps include drying, grinding, dosing, mixing, granule formation, drying, and firing at high temperature. The physical and mechanical properties of the finished samples confirm the differences in the characteristics for the three different compositions, which reflects the influence of the percentage of loam and Ekibastuz SDPP ash on the final material properties. As a result of analysing the physical and mechanical properties of ceramic samples with the addition of Ekibastuz SDPP ash varying from 10 to 30%, it was found that the use of this additive increases the strength properties of samples of expanded clay aggregate for road construction after firing at 1,000°C. Therewith, the average density of the samples decreases, forming a porous structure, which indicates the processes of sintering and crystallisation in ceramic masses when using ash.

The findings obtained show changes in the microstructure of the samples, reflecting the effect of the additive on the formation of porous and durable granule structure. Clay is favoured in construction because of its high plasticity, thermal insulation, environmental sustainability, and decorative possibilities. Compared to slate and granite, clay offers ease of moulding, effective thermal insulation, naturalness, and aesthetically pleasing design. Further research can be directed towards the optimisation of the production process of clay-based granular ceramic aggregate, analysis of its effect on the mechanical properties of concrete, and the search for new methods to improve the performance of concrete structures using this material.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Astakhova, N., & Astakhov, V. (2024). Protective properties of slag and pumice concrete and slag concrete towards steel reinforcement. *Mining Journal of Kryvyi Rih National University*, 22(1), 73-77. doi: 10.31721/2306-5435-2024-1-112-73-77.

[2] Bandura, L., Pałka, K., Leśniak, M., & Franus, W. (2024). Microstructural characteristics and the influence of the chemical composition of the raw material mixture on the physical and chemical characteristics of waste ceramic aggregates. *Journal of Building Engineering*, 84, article number 108376. doi: 10.1016/j.jobe.2023.108376.

[3] Bekkaliev, N., Shakeshev, B., & Chumachenko, N. (2021). Use of secondary resources for the production of building materials. *Bulletin of West Kazakhstan Innovative Technological University*, 3(19), 10-13.

[4] Bumanis, G., Bajare, D., Korjakins, A., & Vaičiukynienė, D. (2022). Sulfate and freeze-thaw resistance of porous geopolymer based on waste clay and aluminum salt slag. *Minerals*, 12(9), article number 1140. doi: 10.3390/min12091140.

[5] Cantero, B., Sainz-Aja, J., Yoris, A., Medina, C., & Thomas, C. (2021). Resonance fatigue behaviour of concretes with recycled cement and aggregate. *Applied Sciences*, 11(11), article number 5045. doi: 10.3390/app11115045.

[6] Dos Reis, G.S., Quattrone, M., Ambros, W.M., Grigore Cazacliu, B., & Hoffmann Sampaio, C. (2021). Current applications of recycled aggregates from construction and demolition: A review. *Materials*, 14(7), article number 1700. doi: 10.3390/ma14071700.

[7] Ghonaim, S., & Morsy, R. (2023). Utilization of ceramic waste material as cement substitution in concrete. *Buildings*, 13(8), article number 2067. doi: 10.3390/buildings13082067.

[8] Hotovkin, A. (2023). *Complex use of metallurgical slags in the production of building materials*. (Master's dissertation, Zaporizhzhia National University, Zaporizhzhia, Ukraine).

[9] Jones, L., & Urbano Gutiérrez, R. (2023). Circular ceramics: Mapping UK mineral waste. *Resources, Conservation and Recycling*, 190, article number 106830. doi: 10.1016/j.resconrec.2022.106830.

[10] Kanagaraj, B., Anand, N., Praveen, B., Kandasami, S., Lubloy, E., & Naser, M.Z. (2023). Physical characteristics and mechanical properties of a sustainable lightweight geopolymer based self-compacting concrete with expanded clay aggregates. *Developments in the Built Environment*, 13, article number 100115. doi: 10.1016/j.dibe.2022.100115.

[11] Khrystych, O. (2023). Fillers for construction mixtures from recycling products of solid inorganic waste. *Modern Technologies, Materials and Structures in Construction*, 20(2), 49-55. doi: 10.31649/2311-1429-2023-2-49-55.

[12] Kolesnikova, I., Suvorov, A., & Bekturganova, N. (2023). Analysis of prospects for the use of local raw materials for the production of self-sealing concretes in the Republic of Kazakhstan. *Bulletin of Kazakh Leading Academy of Architecture and Construction*, 4(90), 110-124. doi: 10.51488/1680-080X/2023.4-08.

[13] Kruglov, O., Menshov, O., Horoshkova, L., & Kruhlov, B. (2023). Magnetic susceptibility of inclined soils and its relationship with some agronomic indicators. *Plant and Soil Science*, 14(1), 39-50. doi: 10.31548/plant1.2023.39.

[14] Kutsenko, A., & Kutsenko, O. (2022). Effect of reinforcement on the crack resistance of concrete slabs. *Machinery & Energetics*, 13(3), 34-42. doi: 10.31548/machenergy.13(3).2022.34-42.

[15] Linchenko, V., Zhuk, D., Lysenko, N., Stepenko, S., & Zhuk, I. (2022). Green energy: Problems of environmental protection. *Ecological Safety and Balanced Use of Resources*, 13(2), 58-68. doi: 10.31471/2415-3184-2022-2(26)-58-68.

[16] Lotero, A., Moncaleano, K.J., & Consoli, N.C. (2021). Alkali-activated red ceramic mixture with waste lime carbide: An alternative alkaline cement made at room temperature. *Journal of Building Engineering*, 65, article number 105663. doi: 10.1016/j.jobe.2022.105663.

[17] Lu, N., Chen, H., Chen, J., & Cao, Y.-F. (2023). Ceramic aggregate material formulated with MSWI fly ash and fuel ash for use as filter media. *Minerals*, 13(7), article number 845. doi: 10.3390/min13070845.

[18] Mahmoodi, O., Siad, H., Lachemi, M., Dadsetan, S., & Sahmaran, M. (2023). Extensive rheological evaluation of geopolymer solutions containing the maximum amount of recycled concrete as precursors and aggregates. *Construction and Building Materials*, 390, article number 131801. doi: 10.1016/j.conbuildmat.2023.131801.

[19] Martins, N.P., Srivastava, S., Simao, F.V., Niu, H., Perumal, P., Snellings, R., Illikainen, M., Chambart, H., & Habert, G. (2021). Exploring the potential for utilization of medium and highly sulfidic mine tailings in construction materials: A review. *Sustainability*, 13(21), article number 12150. doi: 10.3390/su132112150.

[20] Migunthanna, J., Rajeev, P., & Sanjayan, J. (2022). Waste clay bricks as a geopolymer binder for pavement construction. *Sustainability*, 14(11), article number 6456. doi: 10.3390/su14116456.

[21] Montayev, S., & Majit, D. (2021). Ceramic aggregate production perspective for the construction industry. *Science and Education*, 4(65), 230-238. doi: 10.52578/2305-9397-2021-1-4-230-238.

[22] Montayev, S., & Ryskaliev, M. (2020). *Rational technology of ceramdor based on the processing of clay rocks for thermal insulation and structural concrete and road construction: Recommendation*. Uralsk: West Kazakhstan Agricultural University named after Zhangir khan.

[23] Moreno-Maroto, J.M., *et al*. (2023). Can statistical methods optimize complex multicomponent mixtures for sintering ceramic granular materials? A case of success with synthetic aggregates. *Ceramics International*, 49(14(B)), 24195-24206. doi: 10.1016/j.ceramint.2022.09.220.

[24] Nenastina, T., Berezhna, K., Sakhnenko, M., & Buhaievskyi, S. (2024). Degradation of reinforced concrete construction of bridge structures: Corrosion aspect. *Materials Science*, 59(5), 538-545. doi: 10.1007/s11003-024-00809-3.

[25] Nguyen, N.T. (2023). Experimental investigation of creep behaviour of saturated soft clay subjected static loading. *International Journal of GEOMATE*, 25(108), 81-88. doi: 10.21660/2023.108.3894.

[26] Ryltsev, Ye. (2017). *Materials science: A course of lectures*. Kyiv: National Academy of Management Personnel of Culture and Arts.

[27] Shumakov, I., Miroshnikov, V., Younis, B., Buhaievskyi, S., & Bratishko, S. (2024). Improvement of concrete parameters by the method of sodium silicates impregnation by internal vacuum tamping. *IOP Conference Series: Earth and Environmental Science*, 1376, article number 012031. doi: 10.1088/1755-1315/1376/1/012031.

[28] Sithole, N.T., & Mashifana, T. (2020). Geosynthesis of building and construction materials through alkaline activation of granulated blast furnace slag. *Construction and Building Materials*, 264, article number 120712. doi: 10.1016/j.conbuildmat.2020.120712.

[29] Soralump, S., Shah, A., Chaithong, T., Sakai, G., & Boonyatee, T. (2023). Soil strength estimation using screw driving sounding technique for Bangkok clay layers. *International Journal of GEOMATE*, 25(111), 193-201. doi: 10.21660/2023.111.3368.

[30] State Standard of the Republic of Kazakhstan (ST RK) No. 992-96 "State System of Standardisation of the Republic of Kazakhstan. Standardisation of Services. Basic Provisions". (1996, September). Retrieved from https://online.zakon.kz/Document/?doc_id=1051253&pos=2;-104#pos=2;-104.

[31] Tassybekov, Z., Bekenov, T., & Nussupbek, Z. (2020). Assessment of compaction of the road base from repeated exposure to frequently repeated loads of self-propelled road roller. In E. Ginters, M. Ruiz Estrada & M. Piera Eroles (Eds.), *ICTE in transportation and logistics 2019* (pp. 164-170). Cham: Springer. doi: 10.1007/978-3-030-39688-6_22.

Сарсенбек Монтаєв

Доктор архітектури, директор інституту промислових технологій
Західно-Казахстанський сільськогосподарський університет імені Жангір хана
090009, вул. Жангір хана, 51, м. Уральськ, Республіка Казахстан
https://orcid.org/0009-0001-7045-9074

Каржаубай Досов

Старший викладач
Західно-Казахстанський сільськогосподарський університет імені Жангір хана
090009, вул. Жангір хана, 51, м. Уральськ, Республіка Казахстан
https://orcid.org/0009-0001-4771-1008

Нургуль Аділова

Кандидат архітектури, доцент
Західно-Казахстанський сільськогосподарський університет імені Жангір хана
090009, вул. Жангір хана, 51, м. Уральськ, Республіка Казахстан
https://orcid.org/0009-0009-1616-3000

Айнур Монтаєва

Керівник відділу координації наукових досліджень
Кизилординський університет імені Коркит ата
120014, вул. Айтеке бі, 29А, м. Кизилорда, Республіка Казахстан
https://orcid.org/0000-0001-9536-3442

Майра Алмагамбетова

Кандидат інженерних наук, доцент
Західно-Казахстанський сільськогосподарський університет імені Жангір хана
090009, вул. Жангір хана, 51, м. Уральськ, Республіка Казахстан
https://orcid.org/0009-0001-6397-8132

Технологія гранульованого керамічного заповнювача для бетона на основі глин Атирауського родовища Західного Казахстану

Анотація. Метою цього дослідження було вивчення технології гранульованого керамічного заповнювача на основі глини Атирауського родовища, з акцентом на поліпшення механічних і термічних властивостей бетону для досягнення найкращої ефективності та стійкості в будівництві. Методи, використані в цьому дослідженні, включали хімічний аналіз, рентгенофазовий аналіз, електронну мікроскопію. За допомогою цих методів були визначені фізико-механічні та хіміко-мінералогічні характеристики керамічного заповнювача. У дослідженні представлені шляхи вирішення проблеми забезпечення будівельної галузі Західно-Казахстанської області. Виділено ключові характеристики матеріалу, його структурні особливості та вплив на властивості бетону. У дослідженні представлені помилки, що виникають при застосуванні технології гранульованого керамічного заповнювача, і виявлені причини їх виникнення. Проаналізовано функціонування технології, що є критично важливим для визначення її ефективності, потенціалу для розвитку та виявлення можливих покращень у роботі відповідних галузей. Обговорено оцінку експлуатаційних характеристик бетону з гранульованим керамічним заповнювачем, обґрунтування застосування цього матеріалу, обмеження у використанні та вплив цих обмежень на якість кінцевого продукту. В результаті дослідження були запропоновані рекомендації, спрямовані на оптимізацію процесу застосування гранульованого керамічного заповнювача, підвищення надійності бетону та врахування низки факторів, що впливають на виробничі та експлуатаційні аспекти

Ключові слова: будівництво; природні ресурси; експлуатація; компонент; інженерна система