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RESEARCH ARTICLE

ON THE SEISMIC RESISTANCE OF BRICK BUILDINGS BASED ON EXPANDED CLAY WITH COAL MINING WASTE AND INORGANIC ADDITIVES

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Abstract. *Lightweight double-layer concrete walls with a 6-8 cm thick structural concrete layer are effective in earthquake-resistant construction. The development of lightweight concrete production is particularly important for Southern Kazakhstan due to its high seismicity. Reducing the weight of individual structures, as well as buildings and structures as a whole, through the use of lightweight expanded clay concrete can be considered as a measure to improve their seismic resistance. The study examines the effect of inorganic additives and coal mining waste as swelling intensifiers in expanded clay production to improve the seismic resistance of brick buildings. The material composition of the clays studied, as well as the mineralogical and structural properties of the constituent mineral phases, were studied using electron microscopy. Experimental firings of Kyngrak-Keles bentonite clay samples were conducted with the addition of the following mineral salts and non-ferrous metallurgy waste: sodium chloride, calcium chloride, polymetallic ore beneficiation waste, and coal mining waste. It was found that with the addition of 0.5% NaCl and a firing temperature of 1180°C, the resulting expanded clay has a bulk density of 0.89 g/cm^3, which corresponds to a bulk density of 580 kg/m^3. With the addition of 0.5% $CaCl_2$, the bulk density at the same temperature is 0.99 g/cm^3 (bulk density is 650 kg/m^3).*

Keywords: *seismic resistance of brick buildings, inorganic additives, coal mining waste, swelling intensifiers, expanded clay.*

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ҒЫЛЫМИ МАҚАЛА

КӨМІР ӨНДІРУ ҚАЛДЫҚТАРЫ МЕН БЕЙОРГАНИКАЛЫҚ ҚОСПАЛАРЫ БАР КЕРАМЗИТ НЕГІЗІНДЕГІ КІРПІШ ҒИМАРАТТАРДЫҢ СЕЙСМИКАЛЫҚ ТӨЗІМДІЛІГІ ТУРАЛЫ

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Аңдатпа. *Жер сілкінісіне төзімді құрылыста 6-8 см қалың құрылымдық бетон қабаты бар жеңіл екі қабатты бетон қабырғалары тиімді. Жеңіл бетон өндірісін дамыту Оңтүстік Қазақстан үшін сейсмикалық жоғары болғандықтан ерекше маңызды. Жеңіл керамзит бетонды қолдану арқылы жекелеген құрылымдардың, сондай-ақ жалпы ғимараттар мен құрылыстардың салмағын азайту олардың сейсмикалық төзімділігін арттыру шарасы ретінде қарастырылуы мүмкін. Зерттеулер кірпіш ғимараттардың жер сілкінісіне төзімділігін арттыру үшін керамзит өндірісіндегі бейорганикалық қоспалар мен көмір өндіретін қалдықтардың әсерін зерттеуге арналған. Зерттелетін саздардың заттық құрамы, минералды фазалардың құрамдас бөліктерінің минералогиялық және құрылымдық ерекшеліктері электронды-микроскопиялық талдау арқылы зерттелді. Келесі минералды тұздар мен түсті металлургия қалдықтары: натрий хлориді, кальций хлориді, полиметалл кендерін байыту қалдықтары, сондай-ақ көмір өндіру қалдықтары қосылған Қыңғрақ-Келес бентонит саздарының үлгілерін эксперименттік күйдіру жүргізілді. 0,5% NaCl және 1180^{0}С күйдіру температурасын енгізген кезде алынған кеңейтілген саздың түйіршіктегі көлемдік массасы 0,89 г/см^3 болатыны анықталды, бұл кеңейтілген саздың 580 кг/м^3 көлемдік массасына сәйкес келеді. 0,5% $CaCl_2$ қоспасымен бірдей температурадағы көлемдік масса 0,99 г/см^3 (жаппай масса 650 кг/м^3).*

Түйін сөздер: *кірпіш ғимараттардың сейсмикалық төзімділігі, бейорганикалық қоспалар, көмір өндіру қалдықтары, ісіну күшейткіштер, керамзит.*

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НАУЧНАЯ СТАТЬЯ

О СЕЙСМОСТОЙКОСТИ КИРПИЧНЫХ ЗДАНИЙ НА ОСНОВЕ КЕРАМЗИТА С ОТХОДАМИ УГЛЕДОБЫЧИ И НЕОРГАНИЧЕСКИХ ДОБАВОК

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Аннотация. *Легкобетонные двухслойные стены со слоем конструктивного бетона толщиной 6-8 см эффективны в условиях сейсмостойкого строительства. Особое значение для Южного Казахстана приобретает развитие производства легких бетонов в связи с высокой их сейсмичностью. Снижение веса отдельных конструкций, а также зданий и сооружений в целом за счет применения легких бетонов из керамзита может рассматриваться как одна из мер повышения их сейсмостойкости. Исследования посвящены изучению влияния неорганических добавок и отходов угледобычи как интенсификаторов вспучивания в производстве керамзита для повышения сейсмостойкости кирпичных зданий. Вещественный состав исследуемых глин, минералогические и структурные особенности составляющих минеральных фаз был изучен с помощью электронно-микроскопического анализа. Были проведены экспериментальные обжиги образцов из кынграк-келесских бентонитовых глин с добавкой следующих минеральных солей и отходов цветной металлургии: хлористого натрия, хлористого кальция, отходы обогащения полиметаллических руд, а также отходов угледобычи. Установлено, что при введении 0,5% NaCl и температуре обжига 1180^{0}C полученный керамзит имеет объемную массу в грануле 0,89 г/см^3, что соответствует насыпной массе керамзита, равной 580 кг/м^3. При добавке 0,5% $CaCl_2$ объемная масса при той же температуре равна 0,99 г/см^3 (насыпная масса равна 650 кг/м^3).*

Ключевые слова: *сейсмостойкость кирпичных зданий, неорганические добавки, отходы угледобычи, интенсификаторы вспучивания, керамзит.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

The authors declare that no generative artificial intelligence technologies or AI-based tools were used in the preparation of this article.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

Авторлар мақаланы дайындау барысында генеративті жасанды интеллект технологиялары мен жасанды интеллектке негізделген технологияларды пайдаланбағанын мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

Авторы заявляют о том, что при подготовке статьи не использовались технологии генеративного искусственного интеллекта и технологии, основанные на искусственном интеллекте.

1 INTRODUCTION

Massive housing construction in large cities with unfavorable engineering and geological conditions and extremely limited expansion potential places high demands on the reliability and cost-effectiveness of multi-story buildings and structures constructed in high-seismic zones. In recent decades, earthquake engineering specialists have been working to develop and apply new methods for seismic insulation of brick buildings and structures. In today's construction environment, reducing the weight of building structures through the use of lightweight concrete and ceramic materials, including expanded clay, is particularly important. This will contribute to improving the seismic resistance of brick buildings **(Hafner et al., 2023)**.

For most artificial aggregates, obtaining granules with the required density depends on the amount of gaseous products released or introduced and retained in the pyroplastic mass. One such gaseous product, iron and calcium oxides, can be one example. Iron oxide (Fe_2O_3), converted to a ferrous state as a result of reduction processes, reacts vigorously with aluminum and silicon oxides, forming a series of eutectics and solutions of complex composition and exerting a strong fluxing effect. One such compound of iron oxide (FeO) with silica is fayalite, which melts at 1205°C, i.e., within the temperature range for producing expanded clay. Also possessing high wetting capacity, FeO promotes the formation of a system with optimal softening parameters, enabling intense and complete swelling. Clays containing iron in the form of oxides and hydroxides exhibit good swelling properties. Calcium oxide shortens the swelling range of the rock, and at high concentrations, by sharply reducing the viscosity of the liquid phase over a short temperature range, it causes rapid deformation and adhesion of the material, complicating firing. Alkali and alkaline earth oxides also participate in the formation of eutectic melts, with their fluxing effect decreasing in the order Na_2O, K_2O, FeO, CaO, and MgO. Clay minerals such as montmorillonite, mica, and hydromica can also be sources of gas formation **(Zhakipbayev et al., 2021)**.

The following features of the production of artificial porous fillers can be noted:

– raw material porosity during heat treatment is caused by the release of gaseous products into the raw material during firing;

– swelling processes occur in the pyroplastic state of the material, therefore, the viscosity of the liquid phase has the primary influence on swelling;

– high-speed firing of the raw material promotes a shift in gas formation processes to higher temperatures, and the coincidence of these processes with the transition of some of the raw material from a eutectic or near-eutectic composition to a pyroplastic state, which facilitates intense swelling;

– the transition of some of the raw material to a pyroplastic state usually occurs at temperatures no higher than 1250°C.

Clays suitable for expanded clay production should not exceed 30% dust content, should not contain carbonates with a grain size greater than 0.2 mm, and should not contain more than 1-2% organic inclusions. However, the limited availability of such raw materials and the need to ensure the cost-effectiveness of the process raise the question of using additives and industrial waste whose chemical composition meets the requirements for expanded clay raw materials. It is known that inorganic substances containing alkaline and alkaline earth element compounds promote the formation of a liquid phase at low temperatures. Therefore, the addition of mineralizers to the batch can reduce the temperature at which the mass transitions to a pyroplastic state or the firing temperature of expanded clay. In order to reduce the firing temperature and intensify swelling, experimental firings of samples of Kyngrak-Keles bentonite clays were carried out with the addition of the following mineral salts and non-ferrous metallurgy waste: sodium chloride, calcium chloride, polymetallic ore beneficiation waste, and coal mining waste **(Seiitkassymuly et al., 2025)**.

2 LITERATURE REVIEW

A study **(Gulfem et al., 2022; Vandanapu et al., 2018)** assessed the feasibility of using coal mining waste as a raw material for brick production. Dry-crushed waste was added to clay in proportions ranging from 0 to 100%, and the samples were fired at temperatures up to 1150°C. All resulting bricks met Turkish strength standards, confirming the suitability of the waste as an alternative building material and offering an environmentally friendly solution to its disposal.

The authors' study **(Xiaogang et al., 2025; Kalman Šipoš et al., 2019)** proposes a method for assessing the seismic resistance of buildings damaged by mining activities based on energy dissipation theory. It was found that ground subsidence reduces the rigidity of buildings, lengthens their natural period, and amplifies torsional vibrations under seismic loads. Numerical modeling showed an increase in displacements and internal forces, especially on the lower floors. As a solution, they propose a protection system combining underground backfill and surface isolation, providing practical guidance for seismic design in mining areas.

The authors **(Soumitra et al., 2024; Khan et al., 2023)** explore a new approach to the design of clay brick structures based on extensive shear testing, developing numerical models and failure criteria, which improves the accuracy of calculations and the reliability of buildings such under seismic loading. Modern brick buildings must not only meet architectural and functional requirements but also be effectively designed for structural stability, energy efficiency, and seismic resistance. However, the complex combination of these requirements makes testing their behavior under seismic loads challenging.

A research **(Mohammad Ali Esmaili-Tafti et al., 2025; Chourasia et al., 2020)** first analyzed the seismic performance of cold-formed steel frame (CFSF) shear walls constructed using different installation methods and stud spacings. Six walls, varying in size, brick placement order, and the presence of insulation, were fabricated and tested. The results showed that simultaneous wall construction and increased stud spacing increased shear strength but had little effect on seismic performance. The Wang and Pauli methods also yielded similar design parameters.

A study **(Shoaib Ur Rehman et al., 2025; Agrawal et al., 2021)** examines the use of confined masonry structures (CBMS) to improve the seismic performance of residential buildings. A comparative numerical analysis of CBMS, traditional masonry structures (CMS), and framed structures (FS) revealed that CBMS exhibit the lowest deformations and displacements under seismic loading. Due to their concrete infill, such walls exhibit increased ductility and stability, offering an effective solution for mitigating seismic damage.

A research work **(As'at Pujianto et al., 2024; Bagnoli et al., 2021)** examined the technical properties of lightweight concrete with expanded clay aggregate for improving the seismic resistance of infrastructure. Experiments showed that the oval aggregate shape provides superior strength and density characteristics, while the optimal amount of superplasticizer (up to 2.5%) improves the properties of both fresh and hardened concrete. The results confirm the potential of expanded clay as an environmentally friendly and effective material for lightweight seismic-resistant structures.

3 MATERIALS AND METHODS

The Turkestan region is one of the richest in expanded clay raw materials with the location of large and very promising for the development of such deposits of bentonite and bentonite-like clays as Kyngrak-Keles. These clays consist mainly of minerals of the montmorillonite group $Al_2[Si_4O_{10}](OH)_2 \cdot nH_2O$ and are capable of swelling during firing. The chemical composition of the Kyngrak-Keles bentonite clays is represented by the composition (%): SiO_2 - 63.0; Al_2O_3 - 13.0; Fe_2O_3 - 5.40; CaO - 4.48; MgO - 3.35; K_2O - 2.0; Na_2O - 1.45; TiO_2 - 0.95; FeO - 0.85; SO_3 - 5.55.

For a more in-depth study of the material composition of the clays under study, the mineralogical and structural features of the constituent mineral phases, electron microscopic analysis was used on a scanning electron microscope SEM JSM-6490LV, where we recorded the following elements: Si; O; Fe; K; Mg; Ca **(Figure 1)**.

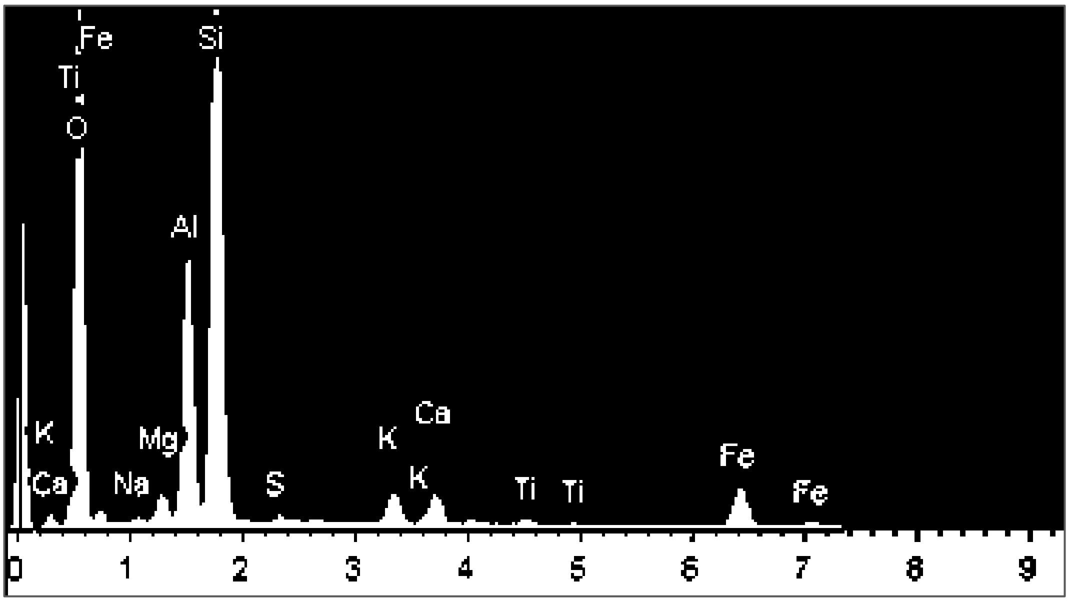

Figure 1 – Energy-dispersive SEM spectrum of Kyngrak-Keles bentonite clays

Figure 1 shows the characteristic presence of iron oxide in the studied clays. Iron oxide, converted to a ferrous state as a result of reduction processes, actively reacts with aluminum and silicon oxides, forming a series of eutectics and solutions of complex composition, while exerting a strong fluxing effect. Also possessing greater wetting capacity, FeO promotes the formation of a system with optimal softening parameters, which facilitates intensive and complete swelling.

4 RESULTS AND DISCUSSION

The results of tests of expanded clay obtained from Kyngrak-Keles bentonite clays with the introduction of mineral additives are shown in **Table 1** and **Figures 2 and 3**.

Table 1
Physical and mechanical properties of expanded clays based on Kyngrak-Keles bentonite clays with the introduction of inorganic additives

Burning temperature, ^{0}C	Swelling coefficient		
	0,5% $CaCl_2$	0,5% NaCl	7% of polymetallic ore beneficiation waste
1080	1,02	0,82	1,22
1100	0,95	0,91	1,37
1120	1,03	0,98	1,38
1140	1,30	1,05	1,49
1160	1,33	1,22	1,61
1180	1,52	1,58	1,65
Burning temperature, ^{0}C	**Bulk density, g/cm^3**		
1080	1,48	1,69	1,35
1100	1,52	1,52	1,20
1120	1,44	1,43	1,18
1140	1,18	1,32	1,07
1160	1,15	1,14	0,98
1180	0,98	0,90	0,92

The presented results show that with the addition of 0.5% NaCl and a firing temperature of 1180^{0}C, the resulting expanded clay has a bulk density in granules of 0.89 g/cm^3, which corresponds to a bulk density of expanded clay equal to 580 kg/m^3. With the addition of 0.5% $CaCl_2$, the bulk density at the same temperature is equal to 0.99 g/cm^3 (bulk density is equal to 650 kg/m^3).

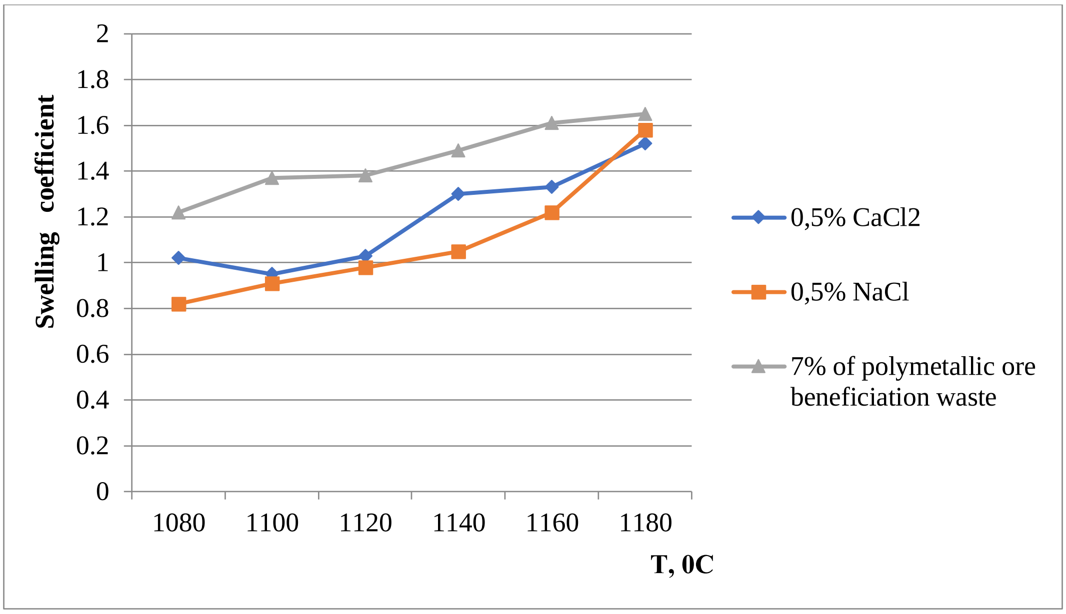

Figure 2 – Change in the swelling coefficient of the obtained expanded clay based on Kyngrak-Keles bentonite clays with the introduction of inorganic additives depending on the firing temperature

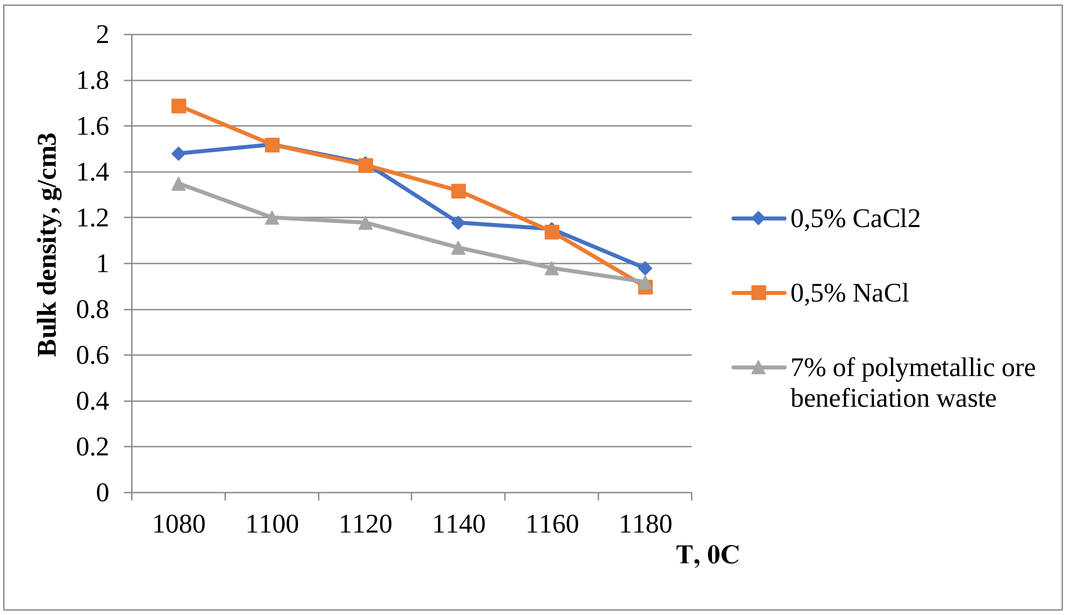

Figure 3 – Change in the bulk density of the obtained expanded clay based on Kyngrak-Keles bentonite clays with the introduction of inorganic additives depending on the firing temperature

When 7% of polymetallic ore beneficiation waste was added, the performance of the resulting expanded clay was inferior to that of expanded clay from pure clay.

Seven masses of coal mining waste were tested in the range of 1-10% additive added. The results presented in **Table 2** and **Figures 4 and 5** indicate that coal mining waste cannot serve as an expanding additive for kyngrak-keles bentonite clays.

Table 2

Physical and mechanical properties of expanded clays based on kyngrak-keles bentonite clays with the addition of coal mining waste

Burning temperature, ^{0}C	% coal mining waste					
	1	3	5	7	10	
1080	0,7	1,0	0,9	0,9	1,0	**Swelling coefficient**
1100	0,9	1,1	1,0	1,1	1,1	
1120	1,1	1,2	1,1	1,2	1,2	
1140	1,3	1,3	1,2	1,3	1,3	
1160	1,6	1,4	1,3	1,4	1,4	
1180	1,7	1,8	1,4	1,5	1,5	
1200	1,8	2,0	1,5	1,6	1,6	
Burning temperature, ^{0}C	**% coal mining waste**					
	1	3	5	7	10	
1080	1,80	1,55	1,60	1,66	1,38	**Bulk density, g/cm^3**
1100	1,69	1,53	1,38	1,32	1,26	
1120	1,56	1,44	1,20	1,16	1,12	
1140	1,32	1,18	1,17	1,04	1,16	
1160	1,12	0,99	0,98	1,03	0,98	
1180	1,05	0,82	0,95	0,86	0,95	
1200	0,98	0,76	0,94	0,85	0,86	

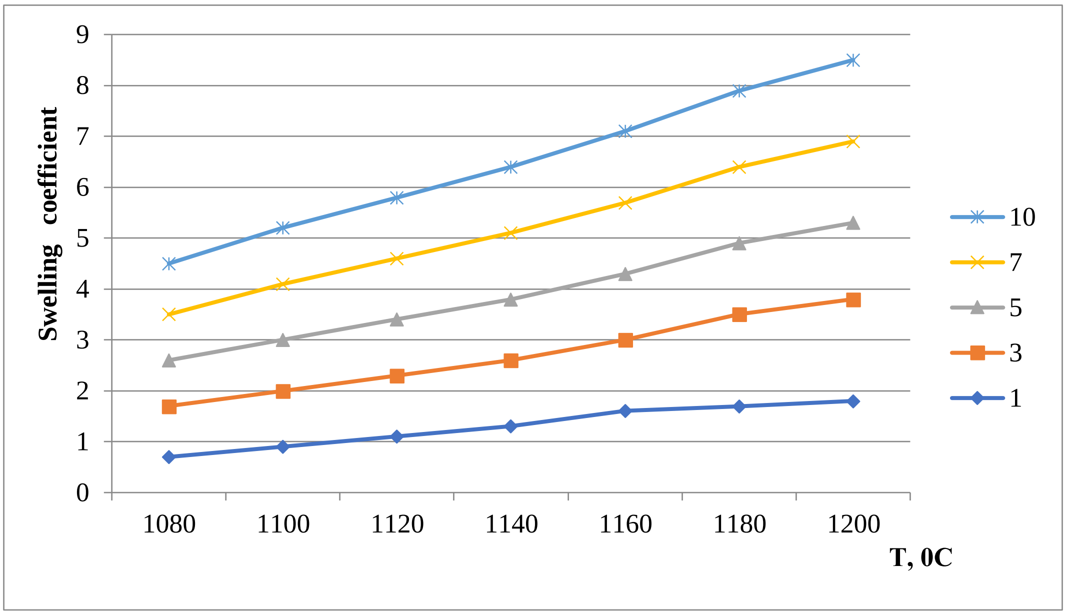

Figure 4 – Change in the swelling coefficient of the obtained expanded clay based on Kyngrak-Keles bentonite clays with the addition of coal mining waste depending on the firing temperature

The addition of 1-10% coal mining waste had virtually no effect on clay expansion. The expansion coefficient was lower, and the bulk density of the granules was virtually identical to those of expanded clay from kyngrak-keles bentonite clays without additives. Only the addition of 7% and 10% coal mining waste slightly decreased the bulk density. Apparently, this additive acts as a leaning agent for the studied clay, but does not promote expansion. The ash residue of the coal mining waste reaches 65-75% of the total mass and, being refractory in nature, shifts the onset of liquid phase formation to higher temperatures. Therefore, at the temperatures accepted for expanded clay firing, the granules do not have time to transform into a pyroplastic state and expand very weakly.

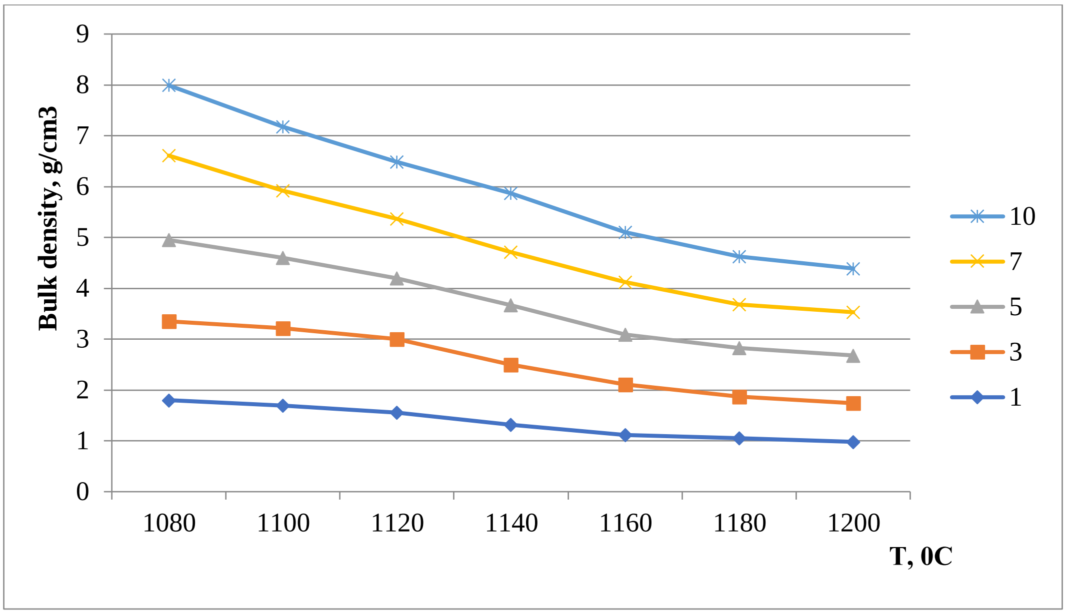

Figure 5 – Change in the bulk density of the obtained expanded clay based on Kyngrak-Keles bentonite clays with the addition of coal mining waste depending on the firing temperature

5 CONCLUSIONS

1. It was found that with the addition of 0.5% NaCl and a firing temperature of 1180^{0}C, the resulting expanded clay has a bulk density of 0.89 g/cm^3 per granule, which corresponds to a bulk density of 580 kg/m^3. With the addition of 0.5% $CaCl_2$, the bulk density at the same temperature is 0.99 g/cm^3 (bulk density is 650 kg/m^3).
2. It was found that the swelling coefficient is lower, and the bulk density of the granules is almost the same as these indicators of expanded clay from Kyngrak-Keles bentonite clays without additives.
3. It has been established that during heat treatment, all clay minerals and fluxes pass into the melt, forming pore walls with the subsequent appearance of a glass phase, where the raw material, already at the maximum temperature, softens due to the formation of ever greater quantities of low-melting eutectics with the participation of fluxes and the assimilation of other finely dispersed components in the melt, after which the mass passes into a pyroplastic state, characterized by a certain homogeneity of the melt and an optimal viscosity for swelling and porization.
4. During heat treatment, under the influence of shrinkage deformations and rearrangement of structural elements, the number and size of pores, as well as the overall porosity of the material, change significantly, mainly determined by the mineralogical composition and degree of dispersion of the original clay raw material, while the finer the clay, the more low-temperature vapor-gas phase is released from the mineralogical components, the greater the microporosity of the material, and vice versa.

Thus, it has been established that for obtaining expanded clay, inorganic additives can only be used in combination with organic ones.

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