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RESEARCH ARTICLE

EXPANDED CLAY LIGHTWEIGHT CONCRETE TO INCREASE THE SEISMIC RESISTANCE OF BRICK BUILDINGS

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Abstract. *Development lightweight concrete production is particular importance for Kazakhstan and for its southern regions due to their high seismicity. In these conditions, reducing weight individual structures, buildings and structures whole through use lightweight expanded clay concrete can be considered one measures to increase their seismic resistance. Lightweight concrete two-layer walls with 6-8 cm thick layer structural concrete effective in seismic-resistant construction or in presence subsidence soils. Results SEM were used in studies to determine morphological structural features bulk studied bentonite clays. Important characteristic clay raw materials fire and air shrinkage, which means decrease in linear dimensions and volume clay sample during its drying. For studied clay, value air linear shrinkage under slow natural drying conditions 10.8%, under harsh artificial drying regime 7.8%. Fire shrinkage during firing samples T=950^{0}C - 5.5%. With introduction 0.5% tire production waste powder into mass, expanded clay with bulk density less than 400 kg/m^3 can be obtained already temperature 1120^{0}C. Granules fired at 1160^{0}C have bulk density 0.484 g/cm^3 - bulk density expanded clay 280 kg/m^3 with closed porosity 77%. Presented results indicate that tire production waste is best additive for production expanded clay from clays in lightweight concrete technology in order to improve seismic resistance brick buildings. It was found that addition tire production waste to clays serves good intensifier swelling. It was confirmed that optimal additive tire production waste is 0.5-1% clay mass. Optimum firing temperature for expanded clay was determined to be 1120^{0}C±20^{0}C.*

Keywords: *bentonite clays, tire waste, expanded clay, swelling, seismic resistance*

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КІРПІШ ҒИМАРАТТАРДЫҢ СЕЙСМИКАЛЫҚ ТӨЗІМДІЛІГІН АРТТЫРУ ҮШІН КЕРАМЗИТТІ ЖЕҢІЛ БЕТОН

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Аңдатпа. *Жеңіл бетон өндірісін дамытудың Қазақстан үшін, әсіресе, сейсмикалық жоғары болуына байланысты оның оңтүстік аймақтары үшін маңызы ерекше. Осы жағдайларда жеңіл керамзит бетонды қолдану арқылы жекелеген құрылымдардың, сондай-ақ жалпы ғимараттар мен құрылыстардың салмағын азайтуды олардың сейсмикалық төзімділігін арттыру шараларының бірі ретінде қарастыруға болады. Құрылымдық бетонның қалыңдығы 6-8 см қабаты бар жеңіл бетонды екі қабатты қабырғалар сейсмикалық төзімді құрылыста немесе шөгу топырақтары болған кезде тиімді. Зерттелетін бентонит саздарының негізгі бөлігінің морфологиялық құрылымдық ерекшеліктерін анықтау үшін зерттеулерде сканерлеуші электронды микроскоптың нәтижелері пайдаланылды. Сазды шикізаттың маңызды сипаттамасы от пен ауаның шөгуі болып табылады, бұл оны кептіру кезінде саз үлгісінің сызықтық өлшемдері мен көлемінің төмендеуін білдіреді. Зерттелетін саз үшін баяу табиғи кептіру жағдайында ауаның сызықтық шөгуінің мәні 10,8%, ал қатал жасанды кептіру режимінде - 7,8% құрайды. Үлгілерді күйдіру кезінде 950^{0}С температурада өрттің шөгуі 5,5% құрайды. Массаға шина өндірісінің қалдық ұнтағының 0,5% енгізген кезде 1120^{0}С температурада көлемді тығыздығы 400 кг/м^3-тен аз керамзит алуға болады. 1160^{0}С күйдірілген түйіршіктердің көлемдік тығыздығы 0,484 г/см^3, бұл 77% жабық кеуектілігімен шамамен 280 кг/м^3 керамзиттің көлемдік тығыздығына сәйкес келеді. Ұсынылған нәтижелер шина өндірісінің қалдықтары кірпіш ғимараттардың сейсмикалық төзімділігін арттыру мақсатында жеңіл бетон технологиясында бентонит саздарынан керамзит өндіру үшін ең жақсы қоспа болып табылатынын көрсетеді. Бентонит саздарына шина өндірісінің қалдықтарын қосу ісінуді жақсы күшейтетіні анықталды. Шина өндірісінің қалдықтарының оңтайлы қоспасы балшық массасының 0,5-1% құрайтыны расталды. Керамзит үшін оңтайлы күйдіру температурасы 1120^{0}С ± 20^{0}С болып анықталды.*

Түйін сөздер: *бентонит саздары, шина қалдықтары, керамзит, ісіну, сейсмикалық төзімділік*

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НАУЧНАЯ СТАТЬЯ

КЕРАМЗИТОВЫЙ ЛЕГКИЙ БЕТОН ДЛЯ ПОВЫШЕНИЯ СЕЙСМОСТОЙКОСТИ КИРПИЧНЫХ ЗДАНИЙ

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Аннотация. *Развитие производства легких бетонов приобретает особое значение для Казахстана и, в частности, для его южных районов в связи с высокой их сейсмичностью. В этих условиях 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. Легкобетонные двухслойные стены со слоем конструктивного бетона толщиной 6-8 см эффективны в условиях сейсмостойкого строительства или при наличии просадочных грунтов. В исследованиях были использованы результаты сканирующего электронного микроскопа для определения морфологических структурных особенностей основной массы исследуемых бентонитовых глин. Важной характеристикой глинистого сырья является огневая и воздушная усадки, что означает уменьшение линейных размеров и объема глинистого образца при его сушке. Для исследуемой глины величина воздушной линейной усадки в условиях медленной естественной сушки составляет 10,8%, а при жестком режиме искусственной сушки – 7,8%. Огневая усадка при обжиге образцов на температуру 950^{0}С составляет 5,5%. При введении в состав массы 0,5% порошка отходов шинного производства керамзит с насыпной плотностью менее 400 кг/м^3 может быть получен уже при температуре 1120^{0}С. Гранулы, обожженные при 1160^{0}С, имеют объемную массу 0,484 г/см^3, что соответствует насыпной массе керамзитов около 280 кг/м^3 с закрытой пористостью – 77%. Приведенные результаты свидетельствуют о том, что отходы шинного производства являются лучшей добавкой для производства керамзита из бентонитовых глин в технологии легких бетонов с целью повышения сейсмостойкости кирпичных зданий. Установлено, что добавка отходов шинного производства в бентонитовые глины служат хорошим интенсификатором вспучивания. Подтверждено, что оптимальная добавка отходов шинного производства равна 0,5-1% от массы глины. Определена оптимальная температура обжига керамзита 1120^{0}С ± 20^{0}С.*

Ключевые слова:. *бентонитовые глины, отходы шин, керамзит, вспучиваемость, сейсмостойкость*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

АЛҒЫС/ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

1 INTRODUCTION

Following effective seismic codes, common buildings are considered to be made of the same material throughout the story distribution and based on an ideal rigid soil. However, in daily construction practice, there are often cases of buildings formed by a bottom part constructed with reinforced concrete (r/c) and a higher steel part, despite this construction type not being recognized by code assumptions. In addition, soil deformability, commonly referred to as the Soil-Structure Interaction (SSI), is widely found to affect the earthquake response of typical residence structures, apart from special structures, though it is not included in the normative design procedure (**Askouni, 2024**). The normative common building seismic design mainly involves the same structural material throughout the entire building, which rests on ideal rigid supporting soil, following the rules of (**EN 1992-1-1; EN 1993-1-1; EN 1998-5**). The described mixed-in-height structures can be seen in daily construction cases related to projects based on renovating, redesigning, or updating the structural function of buildings.

The current large-scale transition to industrial-innovative development of the construction industry requires the use of lightweight concrete on porous aggregates with low thermal conductivity, sufficient mechanical strength and low density. One of such aggregates, which can be widely used in industry, are insulating expanded claystones based on local bentonite clays. The forecast reserves of bentonite clays only in the Turkestan region are about 160 million tonnes, and in Kazakhstan are more than 10 billion tonnes, in order to obtain from them heat-insulating expanded clay are not yet fully assessed, although they are very interesting and their prospects are obvious in the transition of the Republic of Kazakhstan to a ‘green’ economy to implement the concept of its second direction - energy efficiency of housing and communal services. Prospects of mass purposeful industrial use of bentonite clays for production of expanded clay in the technology of lightweight concrete in order to increase the earthquake resistance of brick buildings are not yet fully assessed, although they are very interesting and their prospects are obvious. The pace of construction in Kazakhstan is increasing year by year, but new apartment buildings with load-bearing brick walls have almost ceased to be commissioned. The main reasons for this are the high estimated cost and duration of construction, so the strong, durable and environmentally friendly brick houses have been replaced by quickly erected panel houses, as well as buildings with a monolithic reinforced concrete frame, in which bricks or other wall materials are used only for the construction of self-supporting walls and partitions. Most of the modern residential buildings with load-bearing brick walls were built in the second half of the 20th century. Today, almost all of these houses require major repairs and seismic testing. The development of lightweight concrete production is of particular importance for Kazakhstan and, in particular, for its southern regions due to their high seismicity. In these conditions the reduction of weight of separate constructions, and also buildings and constructions as a whole at the expense of application of light concretes from expanded clay can be considered as one of measures of increase of their seismic resistance. Lightweight concrete two-layer walls with a layer of structural concrete 6-8 cm thick are effective in conditions of earthquake-resistant construction or in the presence of subsidence soils (**Zhakipbayev et al., 2021**).

Tire production for vehicles is increasing exponentially given the rapidly growing population and transportation development. Substantial rubber waste is produced from waste tires past their service time. Tire waste is nearly proportional to tire production given that the world’s yearly tire production exceeded 2.9 billion tires in 2017. This massive amount of non-biodegradable waste occupies a large area and causes environmental hazards. Burning or using tire as fuel may produce toxic gases that are harmful for environment and may cause destructive pollution of natural air. Tire rubber contains styrene, a strongly toxic component that is highly damaging to humans. Therefore, dumping of waste tires may be very dangerous to human health. Recycling of waste in any way is beneficial. In recent years, researchers have attempted to establish a proper guideline for recycling tire waste in different ways. The global tire recycling market was valued at USD 0.95 billion in

2016 and is expected to grow at a compound annual growth rate of 2.1% during the forecast period. The same report revealed that North America accounts for approximately 31% of the revenue share of the global tire recycling market. In response to the growing environmental concerns, waste tires are now being recycled in a manner that not only benefits the environment but also contributes to economic growth. The energy recovered from waste tires also contribute to the economy of industries in developed countries. Around 6% to 8% of waste tires are being recycled as civil engineering materials in the US and in EU countries, but only around 0.4% of waste tires are being recycled in Australia. Concrete is the most used construction material in the world. Optimizing the cost while maximizing the strength and durability of concrete along with improving the greenness of concrete construction are current global challenges. This issue requires advanced materials that can replace the traditional components of concrete. Given the good strength, ductility, and strain control properties of tire waste, it may be utilized as a substitute for concrete components. Rubber can be applied to concrete and mortar by replacing fine aggregates (FA) and coarse aggregates (CA) or used as binder. The advantages of incorporating crumb rubber (CR) into any engineering cementitious composite (ECC) include lowering the CO_2 emissions and increasing the greenness of the environment. Accumulation of waste is subsequently increased to hazardous levels. Tire waste is one of them that cause serious environmental issues because of the rapid rise in and numerous variations of modern developments worldwide. Thus, recycling waste tire rubber in the form of aggregates as supplementary construction material is advantageous. Inclusion of recycled rubber aggregate (RA) lightens concrete, increases its fatigue life and toughness, advances its dynamic properties, and improves its ductility. Concrete with recycled RA performs well in hot and cold weather and achieved significant results under critical exposure and various loading conditions. Though RuC possesses low mechanical strength in general, specific treatment and additives inclusion can be a good solution to improve those properties reliably (**Gerges et al., 2018; Siddika et al., 2019**).

2 LITERATURE REVIEW

Concrete structures are prone to earthquake due to mass of the structures. The primary use of structural lightweight concrete (SLWC) is to reduce the dead load of a concrete structure, which allows the structural designer to reduce the size of the structural members like beam, column, and footings which results in reduction of earthquake forces on the structure. This paper attempts to predict the seismic response of a six-storied reinforced concrete frame with the use of lightweight concrete. A well-designed six-storey example is taken for study. The structure is modelled with standard software, and analysis is carried out with normal weight and lightweight concrete. Bending moments and shear forces are considered for both NWC and LWC, and it is observed that bending moments and shear forces are reduced to 15 and 20 percent, respectively, in LWC. The density difference observed was 28% lower when compared NWC to LWC. Assuming that the section and reinforcements are not revised due to use of LWC, one can expect large margin over and above MCE (maximum considered earthquake; IS 1893-2016), which is a desirable seismic resistance feature in important structures (**Vandanapu et al., 2018**).

The use of masonry infilled frames is very common for most types of building, accordingly state of the art of masonry infilled frame behaviour in general is known but there is still no suggestion of regulations on how to model or use it properly in structural analysis. The use of neural networks in the civil engineering field is already approved however the application of neural networks for the prediction of infilled frame behaviour is rare. There are only a few studies that have explored this topic. With a lack of available data from experiments of masonry infilled frames and with the uncertainty of numerical modelling, this research area needs to be further investigated. In order to connect most of the previously published data with new valuable conclusions, an experimental database of masonry infilled frames was collected. It was limited to only one-storey, one-bay infilled frames according to the availability and uniformity of the structural type (**Cascardi et al., 2017; Kalman Šipoš et al., 2019**).

The existing non-ductile RC structures built prior to the 1960s–1970s were mainly conceived to carry only vertical loads. As a result, the columns of these structures demonstrate poor overall hysteresis behavior during strong earthquakes, dominated by brittle shear or/and premature excessive slipping of the inadequately lap-spliced reinforcement. The poor overall hysteresis performance of existing RC structures built in the 1960s-1970s or earlier is invariably highlighted in the aftermath of every moderate-to-strong seismic event worldwide. Meanwhile, the catastrophic partial or/and general collapse of these structures, which form the majority of the building stoke in most countries, is extremely common, with immense social and economic impact (**Kalogeropoulos et al., 2019; Kalogeropoulos et al., 2021**).

Lightweight aggregate concrete is an innovative building material used to reduce the self-weight of a high-rise building. Recently, the use of lightweight aggregate in construction is increasing immensely due to its performance during an earthquake. Lightweight aggregate concrete (LWAC) is a solution for the achievement of sustainability in the construction sector, which helps us cut down the overall cost of a project in massive construction work (tall buildings and bridges). Additionally, using various industrial by-products and waste instead of natural aggregate allows us to reduce the negative impact on the environment. The development of lightweight aggregate concrete with its relevance is still prominent. The performance of lightweight aggregate on various properties of concrete is explored in this study. This study shows that the lightweight aggregate and waste materials of less density can be used for structural applications with a strength equivalent to that of normal weight concrete. The application and advantages of LWAC are also discussed in this study. The paper’s overall finding reveals that LWAC can be used in sustainable construction growth and reduce waste by using it as natural aggregate in concrete to maintain environmental sustainability (**De Risi et al., 2018; Agrawal et al., 2021; Bagnoli et al., 2021**).

The current research presents a novel and sustainable load-bearing system utilizing cellular lightweight concrete block masonry walls. These blocks, known for their eco-friendly properties and increasing popularity in the construction industry, have been studied extensively for their physical and mechanical characteristics. However, this study aims to expand upon previous research by examining the seismic performance of these walls in a seismically active region, where cellular lightweight concrete block usage is emerging. The study includes the construction and testing of multiple masonry prisms, wallets, and full-scale walls using a quasi-static reverse cyclic loading protocol. The behavior of the walls is analyzed and compared in terms of various parameters such as force–deformation curve, energy dissipation, stiffness degradation, deformation ductility factor, response modification factor, and seismic performance levels, as well as rocking, in-plane sliding, and out-of-plane movement. The results indicate that the use of confining elements significantly improves the lateral load capacity, elastic stiffness, and displacement ductility factor of the confined masonry wall in comparison to an unreinforced masonry wall by 102%, 66.67%, and 5.3%, respectively. Overall, the study concludes that the inclusion of confining elements enhances the seismic performance of the confined masonry wall under lateral loading (**Chourasia et al., 2020; Zade et al., 2021; Khan et al., 2023**).

3 MATERIALS AND METHODS

Expanded clay is an environmentally friendly heat-insulating material, which are light porous materials of cellular structure in the form of ceramic granules obtained by firing bentonite clay, capable of swelling when quickly heated to a temperature of 1050-1300^{0}C for 25-45 minutes.

Firstly, the bentonite clays were selected and then ground in an ML-1r ball mill in an amount of 10 kg with passing through a shaker with a sieve at the bottom of 1 mm, followed by drying in a desiccator at 30^{0}C.

Prepared in advance and weighed for further experiments, the studied clay together with additives was mixed in an ALS-5 mixer in a dry state, gradually moistening with water until a paste-like consistency was obtained. The mass moistened in this way was kept for 4 hours and then mixed again. Pressed tablets were moulded from the prepared mass by packing method using a hydraulic press PGM-100MG4A, with subsequent drying of the already pressed tablets at a temperature of 100-140^{0}C.

An important characteristic of clay raw materials is fire and air shrinkage, which means the reduction of linear dimensions and volume of the clay sample during its drying. For the studied clay, the value of air linear shrinkage under conditions of slow natural drying is 10.8%, and under severe artificial drying regime - 7.8%. Fire shrinkage when firing the samples at a temperature of 950^{0}C is 5.5%.

The suitability of various clay rocks as raw materials for expanded clay production is determined by their degree of swelling during firing and density of c expanded clay.

Temperature and time regime of thermal preparation of expanded expanded clay in laboratory conditions is presented in **Table 1.**

Table 1
Temperature and time regime of thermal preparation of expanded clay

Stages of synthesis	T, ^{0}C	Burning time, min normal mode
Heating in a drying oven	130	5
Thermal preparation	300	2
Raising the temperature in the furnace	1080-1180	23
Tempering at burning temperature	1080-1180	7
1st cooling stage	900-950	0,5-1
2nd cooling stage	30	7

Thermal preparation of samples was carried out in a muffle furnace, where the samples were heated for 2 minutes to 280-300^{0}C. After thermal preparation, the samples were fired at 1080-1180^{0}C with a temperature rise rate of 10-15^{0}C per minute.

The increase in the volume of raw materials during firing is estimated by the bloating coefficient, which expresses the ratio of the volume of expanded clay to the volume of the initial dry raw material.

According to the swelling coefficient, clay raw materials are divided into weakly swelling ($C_{sw} < 2.5$), medium swelling ($C_{sw} = 2.5$-4.5), well swelling ($C_{sw} > 4.5$).

4 RESULTS AND DISCUSSIONS

According to the data of electron microscopy and X-ray energy-dispersive microanalysis (**Figure 1**), performed at the Department of Silicate and Nanomaterials Technology of the Institute of Physics and High Technologies of the National Research Tomsk Polytechnic University on a scanning electron microscope SEM JEOL JCM-6000 together with the Center for Physic-chemical Research Methods "Laboratory of Electron Microscopy" of the Belarusian State Technological University on a scanning electron microscope SEM JEOL JSM-5610LV at magnifications (x100–x1000), we found that the morphological structural features of the bulk of the studied bentonite clays are represented by microaggregates of a complex structure, consisting of sheet-like associations, forming isometric and slightly elongated ultramicroaggregates, in which clay particles contact each other with basal planes.

Bentonite clays, at swelling temperatures, consist of a crystalline phase, mainly consisting of silica and alumina, the amount of which during the swelling process continuously decreases by 50-70% at the beginning and 1-10% at the end; a liquid phase, consisting of fusible components transferred to the melt and some silica and alumina, the amount of which reaches 90% and higher by the end of the swelling process; and a gaseous phase, varying in composition and amount.

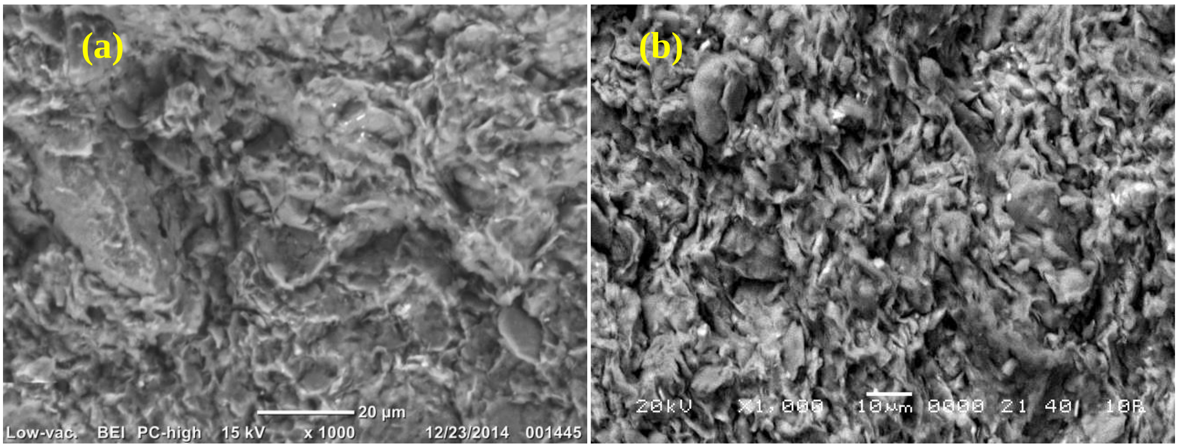

Figure 1 – a) SEM (JCM-6000) and b) SEM (JSM-5610LV) photographic images of the structure and morphological features of the studied fine colloidal dark green bentonite clays.

Differential thermal studies of bentonite clays of the Kyngrak-Keles deposit show (**Figure 2**) that the thermogram has characteristic signs of changes in their properties, where two endoeffects are observed. The first of them is recorded at a temperature of 100-180^{0}C, which is accompanied by a loss of mass and is associated with the release of free and adsorbed water. A small, weakly expressed endothermic effect in the range of 200-900^{0}C is associated with the removal of the main part of chemically bound (constitutional) water of various minerals: montmorillonite, hydromicas, hydrochlorite, kaolinite, micas, gypsum, which causes the absence of a clear endoeffect of their decomposition. In the same temperature ranges, the dissociation of various carbonates with the release of carbon dioxide mainly ends. In the range of 200-600^{0}C, the volatile part of organic impurities is released, and at 700^{0}C and above, sulfur dioxide from gypsum and oxidation of sulfides is released.

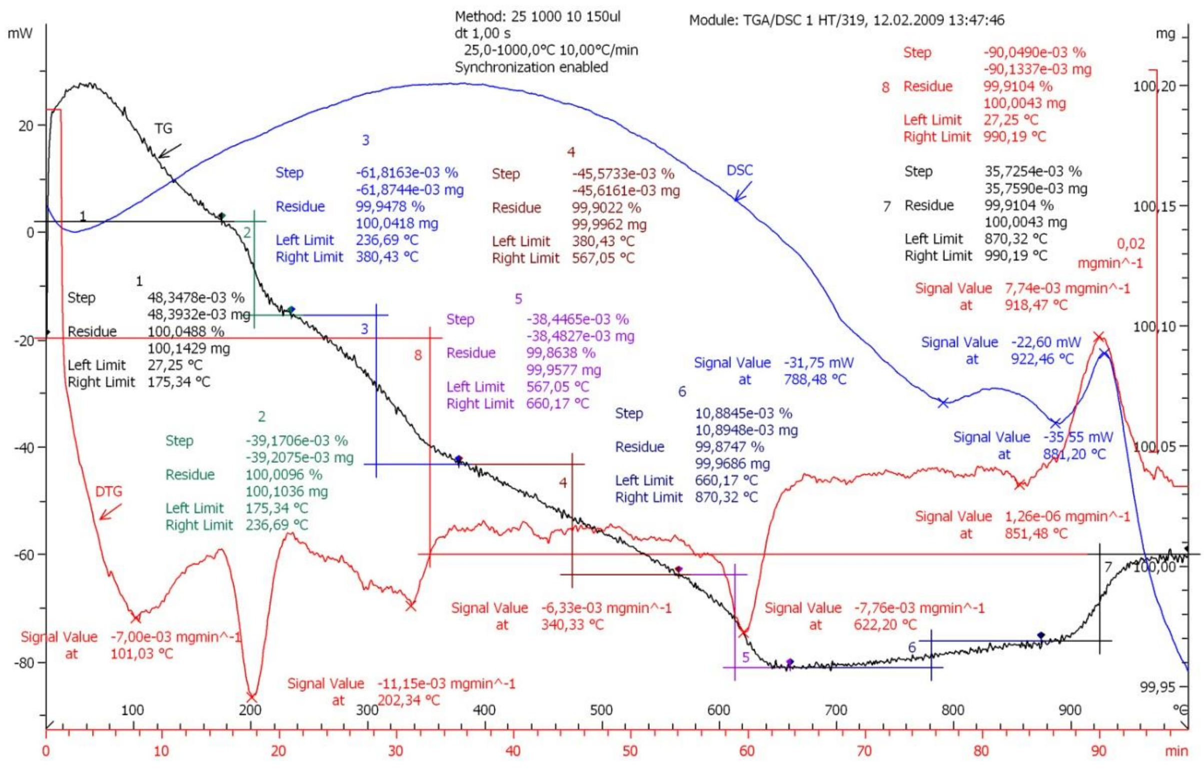

Figure 2 – Thermogram bentonite clays.

In this case, under the influence of reducing conditions, the reactions of interaction of minerals both among themselves and with organic impurities are significantly accelerated, with the release of a gaseous phase. Dehydration during firing is accompanied by a gradual destruction of their crystal lattices - kaolinite at 400-650^{0}C, montmorillonite and hydromica within 300-900^{0}C, and at 900-1050^{0}C, complete destruction of the crystal lattices of clay minerals and their amorphization with the release of residual constitutional water occurs, which increases their reactivity and the formation of a colossal number of micropores, which, along with the pores formed as a result of physical contact between the smallest elementary particles and their complexes, determine the overall porosity of the material in the period preceding its swelling.

Oxidation-reduction processes within the range of 300-1050^{0}C have a significant effect on phase transformations. The presence of organic impurities, iron oxides and constitutional water in the clay raw material creates favorable conditions for the development of reversible reactions with alternate oxidation and reduction of iron oxides, oxidation of carbon and hydrogen and reduction of their combustion products. At the same time, as the temperature increases, reduction reactions begin to predominate, accompanied by the accumulation of iron oxide, which does not disappear until the end of firing. The oxidation process of previously reduced iron begins only when the rate of water vapor release from dehydrating minerals decreases so much that it ceases to interfere with the diffusion of oxygen into the sample.

Research has shown that when firing expanded clay, all clay minerals and fluxes pass into the melt, forming pore walls where at 950-1050^{0}C a glass phase appears with the participation of ferrous oxide and other fluxes and local areas of weakly porous mass. Within the range of 1050-1200^{0}C, the overwhelming majority of expanded clay raw materials soften due to the formation of ever greater quantities of low-melting eutectics with the participation of fluxes, especially ferrous oxide and alkalis, and the assimilation of other finely dispersed components by the melt, and the mass passes into a pyroplastic state, characterized by a certain homogeneity of the melt and an optimal viscosity for swelling.

During the heat treatment, vaporous and gaseous products are released from a homogeneous mixture of minerals of the studied clays. When a homogeneous mixture of minerals of the studied clays is heated, chemical interaction occurs in the contact areas between them while still in solid phases, where, with an increase in temperature, as a result of further interaction of components, a liquid phase appears due to the most easily fusible eutectics and compounds, the amount of which continuously increases due to the appearance of new eutectics at higher temperatures and the interaction of the already formed liquid phase with crystalline components. With the appearance of a certain amount of liquid phase, as the temperature increases, the viscosity of the studied clay mass begins to decrease and plastically deform.

As studies have shown, during the firing process, 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.

As a result of thermal treatment of clays at a rate changing during the firing of expanded clay from 15-30 to 50-100 degrees/min, the reactions of decomposition, dissociation and interaction of the components of the mass with the release of gas-vapor products are somewhat shifted to the region of higher temperatures, providing resources of the gas-vapor phase for swelling of the material, which occurs in the range of 1050-1200^{0}C, to values characteristic of this clay raw material.

As the material is heated to 900-1000^{0}C, the total porosity with a changing nature of the pore size distribution continuously increases, then drops sharply during sintering. At the same time, it is important to note that the total porosity decreases mainly due to larger pores with an increasing number of tiny ones. The swelling interval is reduced by CaO, and at high content it causes rapid deformation and adhesion of the material, sharply reducing the viscosity of the liquid phase in a short temperature range, which significantly complicates burning.

Based on a comprehensive study of bentonite clays from the Kyngrak-Keles deposit, we have established that, based on their material (chemical and mineralogical) composition, bentonite clays belong to the montmorillonite-hydromica low-dispersion group of clay materials with fine-dispersed fractions of less than 10 μm.

Tire production waste is a powder produced during the mechanical processing of tyres. The powder was sieved through a sieve with a mesh size of 2 mm.

The results of tests of expanded clays from masses with the addition of tire production powder, shown in **Table 2** and **Figure 3**, **Figure 4**, indicate a positive effect of this additive on the bulking capacity of the clays under study.

When 0.5% of tire waste powder is added to the mass composition, expanded clay with a bulk density of less than 400 kg/m3 can be obtained already at a temperature of 1120^{0}C. Granules fired at 1160^{0}C have a bulk mass of 0.484 g/cm^3, which corresponds to the bulk mass of expanded clay about 280 kg/m^3 with a closed porosity of 77%.

Table 2

Physical and mechanical parameters of expanded clay on the basis of bentonite clay with the addition of tyre production waste

Burning temperature, ^{0}C	Swelling coefficient	Bulk mass, g/cm^3
0.5% of tyre production waste		
1080	1,8	0,858
1100	2,2	0,736
1120	2,7	0,584
1140	3,1	0,517
1160	3,2	0,484
1% of tyre production waste		
1080	2,3	0,699
1100	3,1	0,513
1120	3,3	0,483
1140	4,2	0,391
1160	4,7	0,353
1180	4,2	0,398
3% of tyre production waste		
1080	2,5	0,626
1100	2,6	0,605
1120	3,5	0,450
1140	3,6	0,430
1160	3,8	0,409
1180	3,6	0,436

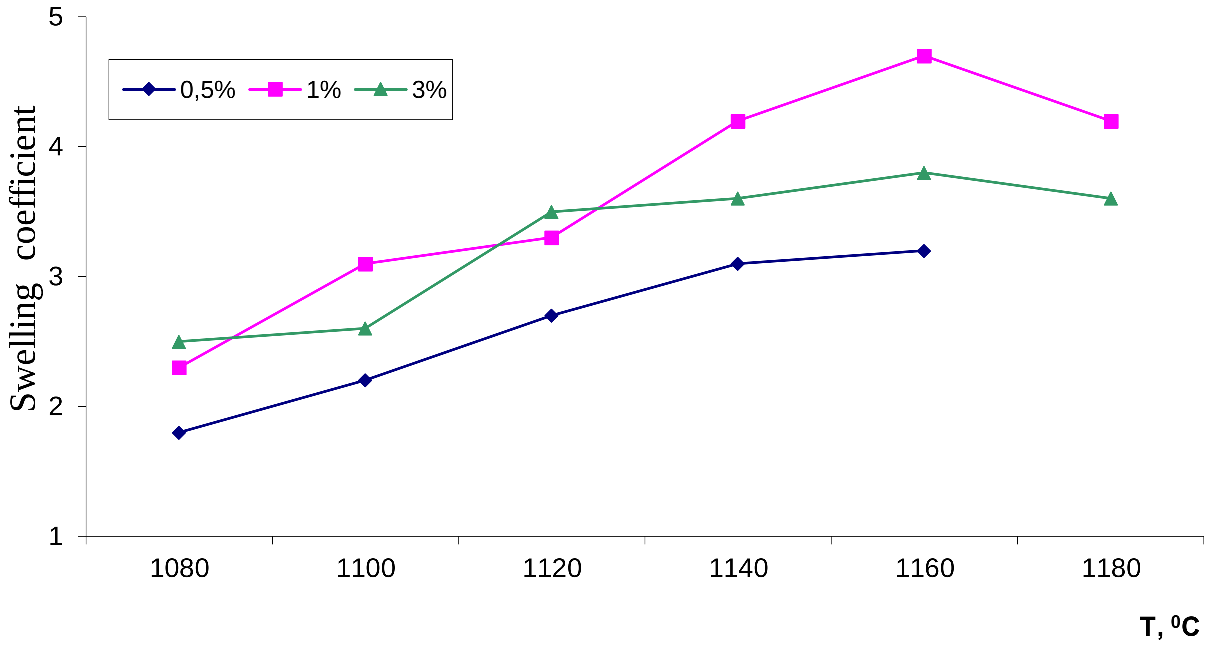

Figure 3 – Change in the swelling coefficient of the obtained expanded clay based on bentonite clays with the addition of tire production waste depending on the burning temperature.

From the mass with the addition of 1% of tire production waste powder, expanded clay can be obtained at a burning temperature of 1100^{0}C and higher. Closed porosity reaches more than 80%. The bulk mass of granules fired at 1160^{0}C = 0.350 g/cm^3, which corresponds to the bulk mass of expanded clay - 280 kg/m^3.

From the mass with the addition of 3% powder from tire production waste, expanded clay can be obtained at a burning temperature of 1080^{0}C. The bulk mass of granules fired at 1080^{0}C = 0.605 g/cm^3, which corresponds to the bulk mass of expanded clay - 400 kg/m^3.

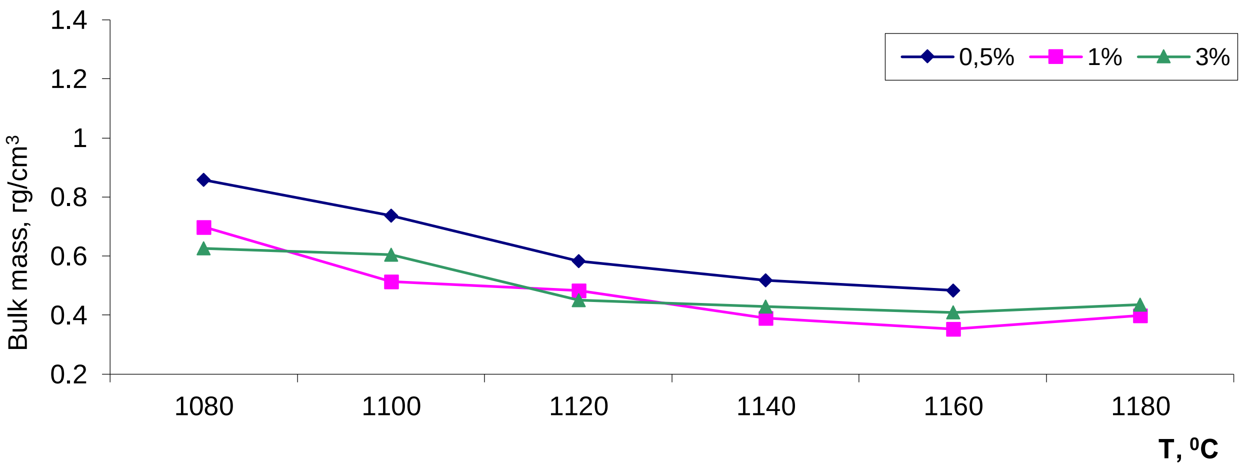

Figure 4 – Change in the bulk mass of the obtained expanded clay based on bentonite clays with the addition of tire production waste depending on the burning temperature.

5 CONCLUSIONS

1. It was established that for the studied clay the value of air linear shrinkage under conditions of slow natural drying is 10.8%, and under a strict artificial drying regime – 7.8%.
2. Fire shrinkage during firing of samples at a temperature of 950^0C is 5.5%.
3. It has been established that the addition of tire production waste to bentonite clays serves as a good swelling intensifier.
4. It has been confirmed that the optimal addition of tire production waste is 0.5-1% of the clay mass.
5. The optimum firing temperature for expanded clay was determined to be 1120^0C ± 20^0C.
6. 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 the melt of other finely dispersed components, 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.

The presented results indicate that tire production waste is the best additive for the production of expanded clay from bentonite clays in lightweight concrete technology to improve the seismic resistance of brick buildings.

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