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PHYSICAL AND MECHANICAL PROPERTIES OF CERAMIC BRICK USING RICE HUSK AND ASH OF THERMAL POWER PLANTS

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The paper presents the results of the influence on shrinkage deformations of the adopted composition during the drying and firing of ceramic bricks made using rice husk and ash of the combined heat and power plant of the city of Kyzylorda of the Republic of Kazakhstan.

The optimal values of the husk additives content and ash from thermal power plants in the studied compositions were determined. Ash dumps from thermal power plants (TPP) create environmental tension and pose a great threat to both the environment and human health. It was found that the hydro-removal ash from the thermal power plant mainly consists of oxides of silica (45.45...46.37 %) and alumina (16.62...17.70 %), there are oxides of calcium (1.66...2.20 %), magnesium (0.86...1.12 %), iron (2.98...3.41 %) and alkali metals (0.80...1.04 %).

The composition of ceramic bricks based on loess-like loam, rice husks, and ash from thermal power plants was studied. The charge composition of the raw components of the "clay, TPP ash, and rice husk" brick: clay is 71...75 %, TPP ash is 18...22 %, and rice husk is 2...6 % of the total mass of the components of the raw mixture of ceramic bricks. The compressive strength of fired ceramic bricks was 11...12 MPa.

According to the results of experimental studies, it was found that the increased concentration of rice husks in natural mixtures is characterized by a stable increase in ceramic mass drying cracks. The increase in time until the appearance of drying cracks is 100 up to 160 sec.

The resulting ceramic brick in accordance with the developed composition has a low weight, good thermal properties and meets the standard requirements for ceramic bricks according to GOST 530-2012

Keywords: ceramic brick, rice husk, ash, shrinkage deformations, technology, thermal conductivity

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1. Introduction

With the growth of the world economy and the planet's population, the need for energy increases sharply. According to experts, from the beginning of 2000 to the present, the total global energy consumption has increased almost 2 times.

This task is solved by creating conditions to ensure a set of measures for the implementation of legal, organizational, scientific, industrial, technical and economic measures aimed at the efficient and rational use of fuel and energy resources and renewable energy sources:

1. One of the promising and priority scientific directions in the production of building materials is the use of industrial waste, including those containing organic components.

2. In general, the use of industrial and agricultural waste of plant origin in the production of building materials subjected to mandatory heat treatment as required by the technological process is a positive scientific trend in terms of energy efficiency of technology and resource conservation.

3. From the point of view of increasing energy efficiency in the production of building materials, the most interesting are the ashes of thermal power plants and agricultural waste – rice husks. Rice husk after burning consists mostly of amorphous silica. Amorphous silica helps to improve the structure of the artificial construction conglomerate and improve the physical and mechanical properties of finished products. It is also a fuel-containing raw material that reduces energy consumption for the production of ceramic bricks.

In this regard, research in this direction can be considered relevant.

2. Literature review and problem statement

In the work [1], the authors classified various solid wastes that are generated as a result of activities and processes in the oil industry. They also analyzed the release of these wastes, which may have adverse effects on the environment and human health. In this regard, the authors [1] took into account the types and sources of solid waste, the characteristics of oily sludges, the toxicity and impact of solid waste, as well as how solid waste is handled in the oil industry. However, the authors did not give the most optimal compositions suitable for the manufacture of ceramic wall materials.

The authors' paper [2] defines technical solutions for the use of rice husk ash and the reuse of mixed cullet to create spherical holes inside ceramics using the foam glass coalescence process. The work presents experimental results obtained in the production of light foam glass granules produced using cullet and rice husk ash. At the same time, the density and strength of fired ceramic bodies were determined [2]. The researchers of this paper touched upon the problem of waste disposal and related costs. The use of waste as an alternative raw material reduces the cost of the final product. But the authors did not consider shrinkage deformations occurring in the sample under study.

The authors' studies provide data on the use of waste in the production of ceramic bricks [3]. The authors conducted experiments in two directions. They applied fired and unfired methods for producing ceramic bricks using waste. Scientists in the paper [3] gave a detailed answer on the use of the potential of waste as a partial or complete replacement of traditional raw materials in the production of bricks. However, the work requires a study of the properties of the resulting brick and technical and economic calculations.

Many authors use organic waste in the production of ceramic bricks. In particular, in the following work, waste was used in experiments instead of clay: eggshell powder, silica dust, ash from rice husks, as well as recycled glass and dry herbs as a fine-grained filler [4]. In the paper, the authors examined only the ash of rice husks. It should be noted that burning rice husks requires fuel or energy.

However, it must be assumed that rice husk can be used as a fuel containing raw materials for the production of ceramic bricks. We believe that the direct introduction of crushed rice husks contributes to the systematic distribution of organic substances in the brick body and at the same time reduces the firing temperature.

The most similar studies are described in [5], where the effect of rice husk and ash from rice husk on the properties of bricks was studied. The authors found that when adding 2 % of rice husk ash from the mass of raw materials, the bricks have the best compressive strength properties of 6.20 MPa. However, they considered only 2 % rice husk content.

Many scientists have been involved in the use of waste from thermal power plants in the production of building bricks. In particular, scientists in [6] presented the results of studies conducted on bricks made from fly ash and slag by an unconventional method. The authors selected the optimal ratio of bottom ash, fly ash, and cement in proportions of 1:1:0.45 [6] to improve the characteristics of bricks. However, in their opinion, it was necessary to take into account the thermal conductivity of the developed brick.

During the processing of rice, a huge amount of waste is generated in the form of rice husks. In rice-producing countries, on average, more than 1 ton of husks are formed upon receipt of 1 ton of product, so there is a serious problem with its disposal [7, 8].

Rice husks are mainly used for agricultural needs (for animal feed up to 70 % of the total volume of husks), in construction as finishing and roofing materials (up to 5 %), and burned directly in the fields (up to 15 %) or simply left in the fields and places of processing for natural decomposition (up to 10 %).

Instead of traditional reinforcement, the researchers in [9] used composite reinforcement, which increases the durability of structures. In terms of energy efficiency, the works [10, 11] are also interesting. The work [10] determined the rational parameters for the heat treatment of a concrete mixture based on a hollow aluminosilicate microsphere. The authors of [11] considered the use of construction waste to produce self-compacting concrete. These works testify to and prove the use of by-products in the production of building materials.

Summarizing the literature review [1–13], it can be stated that the development of resource-saving and energy-efficient building materials that reduce the thermal conductivity of building structures [12] is an urgent task.

3. The aim and objectives of the study

The aim of the study is to identify the physical and mechanical properties of ceramic bricks based on rice husks and ash from thermal power plants. The combined use of three types of raw materials will make it possible to utilize large-tonnage ash dumps and rice husk waste. This will also improve the thermal conductivity of the resulting ceramic sample.

To achieve the aim, the following objectives are accomplished:

– to investigate and determine the physical and chemical characteristics of raw materials;

– to develop a technological scheme for the production of ceramic bricks using rice husks and ashes of thermal power plants;

– to select the charge composition of the raw mixture of ceramic compositions;

– to study the physical and mechanical properties of samples of ceramic bricks.

4. Materials and methods

The object of the study is ceramic samples made of loess-like loam, ash from thermal power plants and rice husk.

The main hypothesis of the study is the integrated use of rice husks and unburned ash particles from thermal power plants as a burnable additive and thereby reducing the average density and thermal conductivity of ceramic bricks.

To simplify the experimental work, the firing temperature of 1000 °C was adopted and 5 compositions of a raw mixture consisting of loess-like loam, CHP ash and rice husk were used. Standard techniques were used to determine the physical and mechanical properties of ceramic bricks.

In experimental work, samples of ash from the Kyzylorda thermal power plant (TPP), loess-like loam, and rice husks were used.

Loam (the Republic of Kazakhstan, central districts of Kyzylorda city) was chosen as the main raw material.

The results of the X-ray phase analysis were obtained using an X-ray diffractometer XPert PRO from PANalytical.

The microstructure of the resulting ceramic shard was examined using a JSM-6390LV scanning electron microscope from JEOL (USA).

In this case, the topography and microstructure of the obtained surface of the samples were studied. As well as qualitative and quantitative analysis of the composition of the sample in the dotted area, and the construction of profiles of the distribution of elements along the selected line.

For the study, the most important performance characteristics of ceramics that are formed during heat treatment, such as fire shrinkage, compressive and bending strength, average density, water absorption, and thermal conductivity, were selected.

To determine the thermal conductivity of ceramic samples, the ITP-MG4 "100" thermal conductivity meter (Russia) was used.

Further scientific and experimental work to identify patterns of changes in physical and mechanical properties depending on the firing temperature was carried out according to the following methodology.

Joint grinding of loess-like loam, CHP ash, and rice husks in a laboratory ball mill until complete passage through a 1- and 2-mm sieve:

a) dosing of raw materials using electronic scales;

b) mixing of the components in a laboratory stirrer with the addition of water;

c) molding of cylinder samples (5×5×5 cm);

d) drying of cylinder samples in a drying oven at a temperature of 70–80 °C to a residual humidity of 4–5 % with a temperature rise rate of 8–10 °C per hour;

e) dried samples were fired in a muffle furnace at temperatures of 1,000 and 1,000 °C with a temperature rise rate of 90–100 °C per hour.

Exposure at the final firing temperature was 1 hour. The samples were cooled with the oven turned off to room temperature; after cooling, the samples were tested to determine their physical and mechanical properties.

5. Results of studies of the dependence of the sensitivity coefficient of air shrinkage on the selected composition of the raw mixture of the ceramic mass

5. 1. Research and determination of physical and chemical characteristics of raw materials

Table 1 presents the chemical composition of loess-like loam from the above region.

According to the content of Al_2O_3, loam belongs to the group of acidic raw materials, and according to fire resistance by the content of Fe_2O_3 to fusible raw materials.

The following figure shows an X-ray image of the loess-like loam under study (Fig. 1).

Table 1

Chemical composition of loess-like loam

Raw material name	Content of oxides, mass %									
	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	P_2O_5	F	SO_3	Na_2O	Loss on ignition
Loess loam	53.0	12.25	11.0	2.13	5.10	–	–	2.57	3.60	9.78

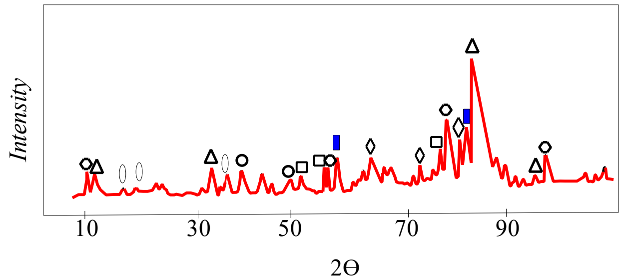


Fig. 1. X-ray image of loess-like loam of the Kyzylorda deposit of the Republic of Kazakhstan. Legend: △ – quartz; ▮ – feldspar; ○ – calcite; 0 – hematite; □ – hydromica; ◊ – kaolinite; ⬡ – montmorillonite

Of the crystalline phases, the clay also contains quartz d/n=(4.23; 3,34; 1.974; 1.813; 1.538)·10^{-10} m, feldspar d/n=(3.18; 2.286)·10^{-10} m, calcite d/n=(2.018; 1.912)·10^{-10} m and hematite d/n=(1.839; 1.686; 1.590)·10^{-10} m. There are also hydromica d/n=(2.08; 2.28; 3.17)·10^{-10} m, kaolinite d/n=(2.304; 4.28)·10^{-10} m, montmorillonite d/n=(1.51; 2.227; 3.02)·10^{-10} m.

The plasticity number of this clay raw material is 10.4 and, according to GOST 9169, it is classified as moderately plastic.

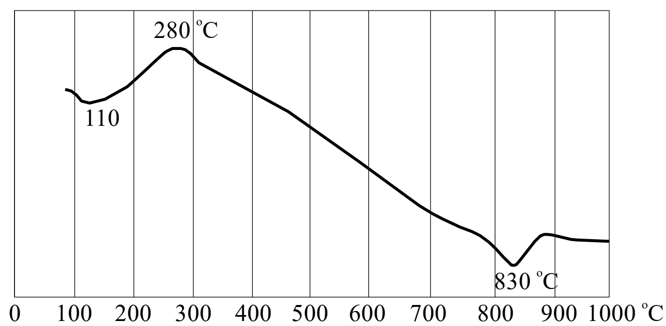


Fig. 2. Thermogram of the studied clay raw material

On the curve of differential thermal analysis (DTA) (Fig. 3) – loam at 120 °C, there is the endoeffect associated with the removal of adsorption water, and the exoeffect at 380 °C corresponds to the combustion of organic impurities. The endothermic effect at 830 °C coincides with the decomposition temperature of calcite with the release of carbon dioxide.

Also, before performing experiments on the production of ceramic bricks, the main properties of TPP ash were investigated and determined.

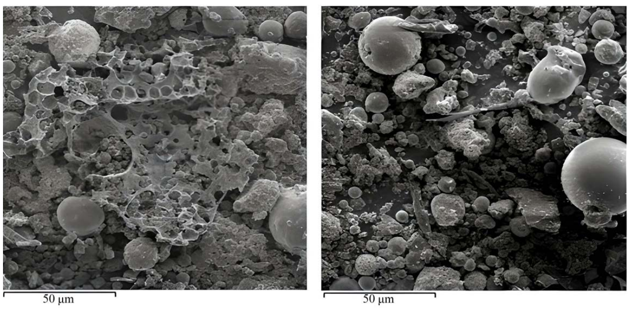
The ash from the hydraulic removal of the Kyzylorda TPP (Table 2) mainly consists of oxides of silica (45.45–46.37 %) and alumina (16.62–17.70 %), there are oxides of calcium (1.66–2.20 %), magnesium (0.86–1.12 %), iron (2.98–3.41 %) and alkali metals (0.80–1.04 %). According to the content of calcium oxide, magnesium oxide, sulfurous and sulfate compounds in terms of SO_3, alkaline oxides of sodium and potassium in terms of Na_2O in the ash component of the ash and slag mixture and the fine-grained mixture, the samples of hydro-removal ash from the Kyzylorda TPP meet the requirements of State Standard 25592-91 "Ash and slag mixtures of thermal power plants for concrete. Specifications".

Table 2

Chemical composition of ash from hydraulic removal from Kyzylorda TPP

No	Content, %										Total SO_3
	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3	
I	0.31	1.12	17.7	46.37	0.19	0.68	2.20	0.91	0.05	3.12	0.78
II	0.26	0.86	16.62	45.45	0.24	0.54	1.79	0.88	0.05	2.98	1.05
III	0.34	0.97	16.62	45.62	0.21	0.70	1.66	0.94	0.05	3.41	0.74

The following (Fig. 3) shows the microstructures of the investigated ashes of thermal power plants.



a *b*

Fig. 3. Microstructures of the investigated ashes of thermal power plants (500x magnification): *a* – sample A; *b* – sample B

Petrographic and microscopic studies of ash samples have shown that four groups of substances can be distinguished in the composition of ash and slag: vitreous, amorphous clay, crystalline and organic. The vitreous substance is represented mainly by spherical formations subjected to hydration. The organic part of the ash is presented in the form of coke and semi-coke.

Currently, in the rice-growing regions of the Republic of Kazakhstan, rice processing wastes and rice husks are dumped into open land areas. They occupy vast territories and impede the cultivation of the land and are exposed to fire, thereby polluting the air mass of the environment.

Studies have shown [13–16] that rice husk is composed of various organic (cellulose, lignin, pentosan, and a small amount of protein and vitamins) and inorganic substances. Moreover, the main component of the inorganic substance of the rice husk part is silica.

According to scientists [13–16], the composition of dried rice husk is as follows in terms of mass, %: inorganic substances are 20; cellulose is 38; lignin is 22; pentosan is 18; other organic substances are 2.

5. 2. Technological schemes for the production of ceramic bricks using rice husks and ashes of thermal power plants

At present, the main directions for the utilization of rice husks are the production of cellulose and its derivative products [7–9]; obtaining silica in crystalline and amorphous forms [13–15]; the use of amorphous silica in the technology of building materials [15].

In brick production technology, burnable additives (sawdust, coal waste, etc.) are often used to increase the porosity of the structure and improve sintering properties, which can significantly reduce the density and increase the heat-shielding properties of products.

In this work, the authors used rice husk as a burnable additive, which, when burned, forms ash in the form of active silica. Active silica contributes to an increase in the strength characteristics of the fired products due to its chemical interaction with the firing products during the firing process.

It should be noted that the degree of activity of the formed silica depends on the nature of the gaseous medium of firing. Studies carried out in the process of obtaining silica in a special installation showed that to obtain amorphous silica of high activity, a two-stage gas mode of burning husks should be used. It includes charring at 120...500 °C of a preliminarily prepared feedstock and oxidative roasting of the resulting ash under fluidized bed conditions in the temperature range from 500 to 800 °C with the supply of oxidizing gas from below through the raw material layer.

It is practically impossible to implement exactly the above process under the conditions of brick production, therefore the authors attempted to model the process of obtaining amorphous silica by dividing it into two separate stages (options).

Two series of samples were prepared by plastic molding using the technological schemes presented below. The schematic diagrams for the production of ceramic products using rice husks and rice husk ash are shown in Fig. 4, 5.

The first option involves burning the husk and obtaining ash outside the kiln, in the air (i.e., in an oxidizing environment), and then using it as an additive in the process of firing the ash-clay composition (Fig. 4).

The process of obtaining ceramic bricks using ash obtained by burning the husk before introducing it into the clay mass consists of the following operations (Fig. 6): clay preparation (coarse and fine processing); ash preparation, which includes pre-washing and burning of husks in an oxidizing environment (in the air); dosage and mixing of the components during their water mixing in the mixer; molding in an extruder, cutting beams; drying and firing at a temperature of 1,000 °C.

The result is a ceramic shard with a highly porous structure and some loss of strength compared to samples on clay without the addition of ash.

The authors used the second option, which involves the introduction of the prepared husk as a burnable additive into the clay composition, followed by firing according to the established temperature regime (Fig. 5).

The process of obtaining ceramic bricks with ash and with rice husk as a burnable additive consists of the following technological operations (Fig. 5): preparation of husk (grinding), clay (coarse and fine processing), dosage, and mixing of components (clay, husk, water) in the mixer, then molding in an extruder, cutting the timber, drying, and firing at a temperature of 1,000 °C. The husk burns out in a reducing environment, resulting in brick with a more highly porous structure, and, accordingly, a loss of strength during the firing process.

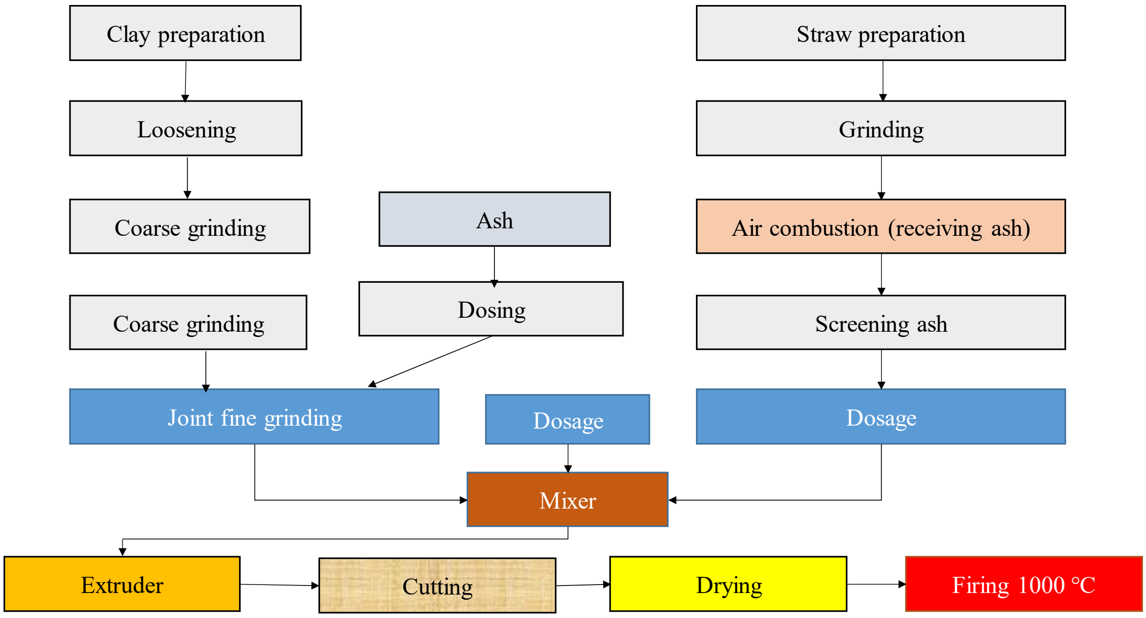


Fig. 4. Flowchart for the manufacture of ceramic products using burnt ash from rice husks

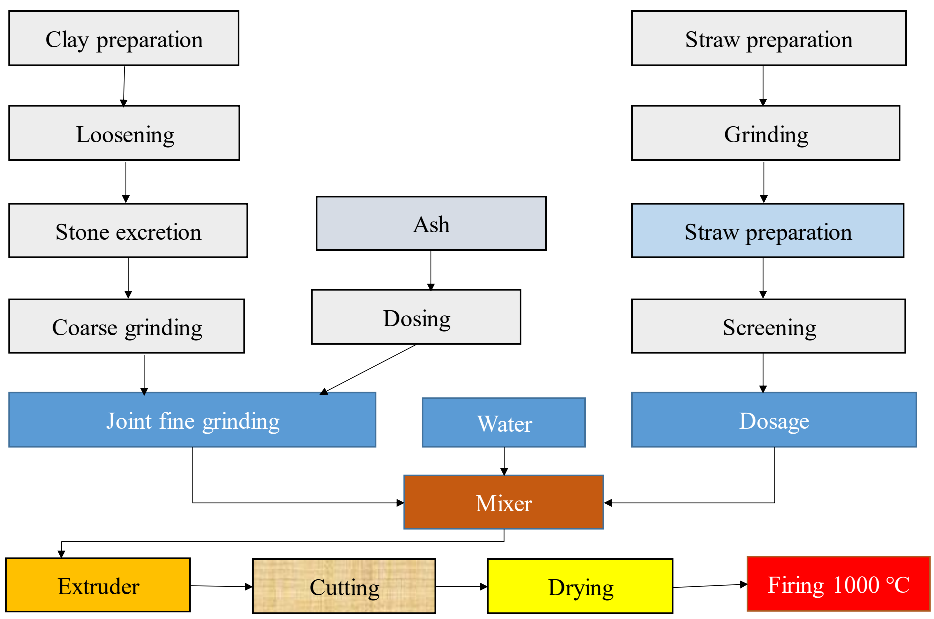


Fig. 5. Flowchart for the manufacture of ceramic products using the rice husk itself

5. 3. Accepted compositions of the raw mixture of ceramic compositions

It is known that the strength of a ceramic shard is affected by its type and the composition of the raw mixture. In this regard, it is necessary to optimize the composition of raw materials, including loess-like loam, ash from thermal power plants, and rice husks.

The strength of ceramic bricks is affected by the composition of raw materials. We have considered 5 compositions of raw materials for the production of ceramic bricks. The composition includes loess-like loam, ash from thermal power plants of the city of Kyzylorda of the Republic of Kazakhstan, and rice husks.

In this regard, the next step is to study the physical and mechanical properties of ceramic bricks made using substandard loess-like loam, TPP ash, and rice husks with various contents of these components.

Therefore, the influence of the composition of the ceramic brick charge of the "loess-like loam – TPP ash – rice husk" system on the final strength of ceramic bricks was studied. The following studied compositions of ceramic masses were adopted (Table 3).

Table 3

Investigated compositions of ceramic masses

Composition number	Content of components, mass %		
	Loam	TPP ash	Rice husk
1	75	22	2
2	74	21	3
3	73	20	4
4	72	19	5
5	71	18	6

The physical and mechanical properties of ceramic bricks were determined depending on the above-mentioned substances added.

5. 4. Physical and mechanical properties of ceramic bricks with the addition of heat and power plant ash and rice husk

Drying sensitivity coefficients and air shrinkage of ceramic specimens were also investigated.

Before the start of heat treatment, experimental studies were carried out to identify patterns of changes in the coefficient of sensitivity to drying and air shrinkage from the composition of the ceramic mass. The results of experimental studies are shown in Fig. 6, 7.

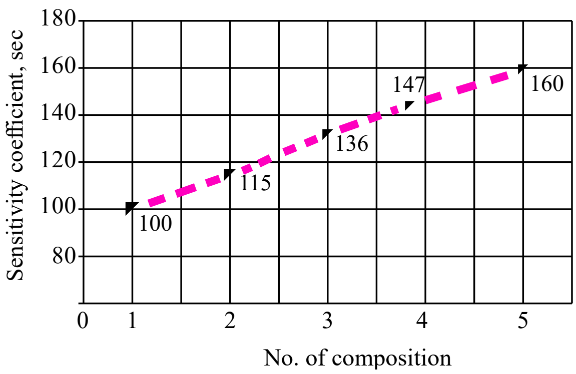


Fig. 6. Dependence of the coefficient of sensitivity to drying on the composition of ceramic masses

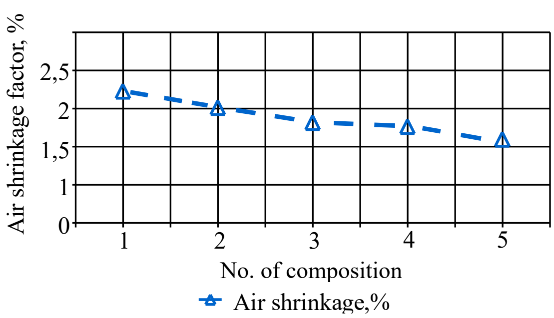


Fig. 7. Dependence of air shrinkage on the composition of ceramic masses

The physical and mechanical properties of ceramic bricks were determined for experimental compositions of ceramic masses. The results of experimental studies are shown in Table 4 and Fig. 8–11.

An indicator of water absorption in the considered case is 14.0–17.1 %. With an increase in the content of rice husks, a decrease in the average density and thermal conductivity of heat-treated samples is observed.

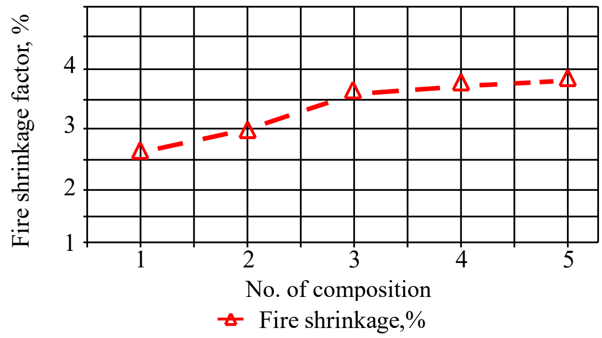


Fig. 8. Dependence of the fire shrinkage of brick samples on the composition of ceramic masses

The fire shrinkage also increases and is in the range of 2.7–3.93 %.

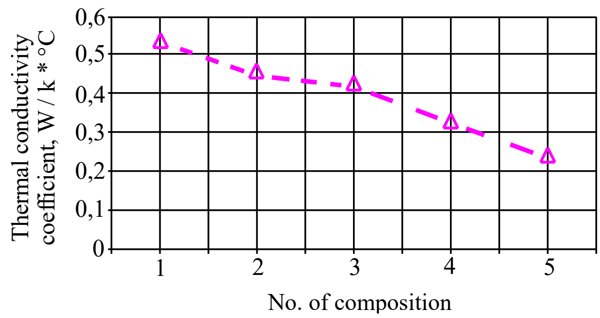


Fig. 9. Dependence of the thermal conductivity of brick samples on the composition of ceramic masses

As can be seen from Fig. 10, the thermal conductivity coefficient is in the range of 0.27–0.52 W/(m·K).

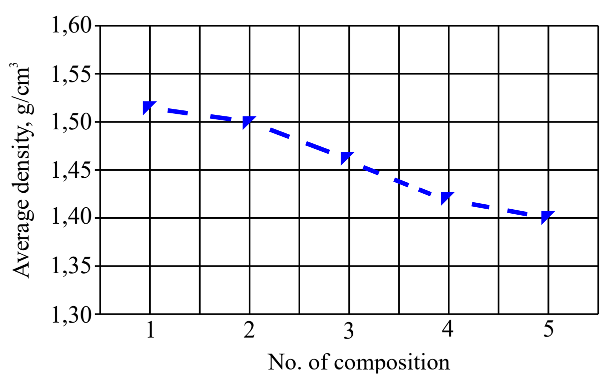


Fig. 10. Dependence of the average density of brick samples on the composition of ceramic masses

It should be noted from Fig. 11 that the average density of ceramic samples is in the range of 1,401–1,512 kg/m^3.

Table 4

Physical and mechanical properties of the studied samples at 1,000 °C

No. of composition	Firing temperature, °C	Average density, kg/m^3	Compressive strength, MPa	Flexural str ength, MPa	Thermal conductivity, W/(m·K)	Water absorption, %	Fire shrinkage, %
1		1,512	12.01	4.4	0.52	14.0	2.7
2		1,500	11.65	3.8	0.46	14.6	3.0
3	1,000	1,440	11.42	3.1	0.41	15.2	3.65
4		1,425	11.22	2.5	0.33	16.4	3.85
5		1,401	11.01	2.3	0.27	17.1	3.93

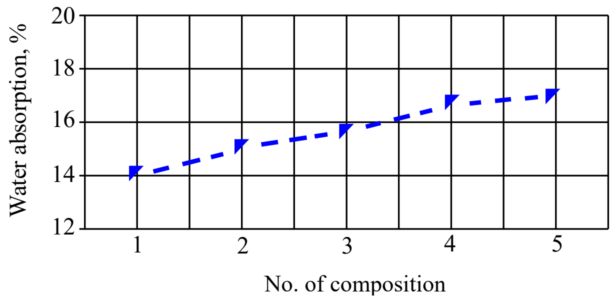
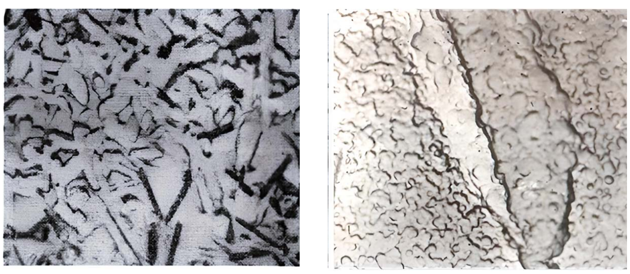


Fig. 11. Dependence of water absorption indicators on the accepted compositions of the raw mixture

From this figure, it can be seen that the water absorption of the obtained ceramic samples is in the range of 14.0–17.0 %.

To determine the regularities of the processes of structure formation in a ceramic composition based on loess-like loams using ash from a thermal power plant and rice husks, studies were carried out using the electron microscopy method (Fig. 12).



a *b*

Fig. 12. Electronic image of a conglomerate mixture: *a* – control sample without rice husks; *b* – test sample

At the same time, those optimal compositions of ceramic compositions that meet the requirements for a set of operational properties and resource and energy saving were subjected to research.

It was also found that heat-treated samples have a uniform fired microporous structure at fracture due to the positive effect of the organo-mineral conglomerate mixture in the composition of ceramic masses based on loess-like loams.

The analysis of electron microscopic studies shows that ceramic masses based on loess-like loams with the addition of heat and power plant ash and rice husk have a more homogeneous and finely porous structure compared to ceramic mass without additives. This is explained by the fact that the organo-mineral conglomerate mixture of rice husk and ash mutually penetrates into the porous space of loess-like loam, forming stable contact bonds.

The electron microscopic image of heat-treated ceramic samples shows numerous micropores formed due to the combustion of the organic part of rice husk and small unburned ash particles of the heat and power plant. It was found that ash in the composition of the ceramic raw material mixture during firing, due to the content of unburned particles, contributes to the formation of heterogeneous crystallization of mullite.

Fig. 13 shows the differential thermal graphs of the studied ceramic masses.

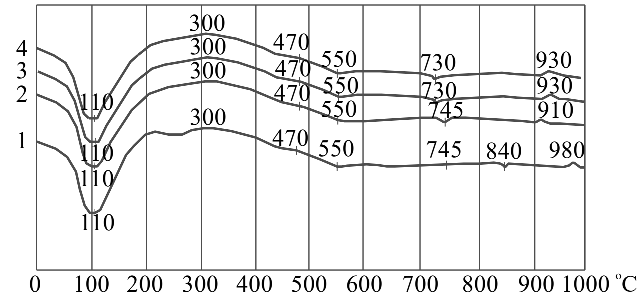


Fig. 13. Differential thermal analysis (DTA) of the studied ceramic masses: 1 – composition No. 1; 2 – composition No. 2; 3 – composition No. 3; 4 – composition No. 4

From the graph of the differential thermal analysis of the adopted ceramic compositions, it can be seen (Fig. 13) that when heated to 110–120 °C, adsorption water is removed from the raw mixture. The endoeffect in the temperature range of 600–660 °C is associated with a complete loss of water and dehydration of clay minerals. The effect at 840–850 °C is associated with the decomposition of carbonates. The exoeffect at 930–980 °C corresponds to the formation of new phases. As can be seen from the figure, the beginning of the process of crystallization of new formations in compositions 2, 3, and 4 shifts from 980 to 930 °C.

The endoeffect in the temperature range of 600–660 °C is associated with a complete loss of water and dehydration of loess-like loam, ash from thermal power plants, and rice husks. The effect at 840–850 °C is associated with the decomposition of carbonates in loess-like loam and ash from power plants. The exoeffect at 930–980 °C corresponds to the reduction of new phases. As can be seen from the figure, the beginning of the process of crystallization of new formations in compositions 2, 3, and 4 shifts from 980 to 930 °C.

In parallel, in the high-temperature range of 700 °C–1,000 °C, the rice husk burns out. Rice husk also plays the role of a fuel-containing component in the clay mass.

6. Discussion of the results of determining deformation shrinkage from the accepted composition

As the results of experimental studies of the sensitivity coefficient to drying of molded samples show, with an increase in the content of an organo-mineral mixture of conglomerates with rice husks, a steady increase in the time of appearance of drying cracks in the ceramic mass is observed. The increase in time until the appearance of drying cracks is from 100 sec up to 160 sec (Fig. 6).

At the same time, these components probably increase the binding and moisture-retaining ability of the ceramic mass, which contributes to a more uniform removal of moisture when exposed to a coolant. As a result, the ceramic mass acquires the ability of crack resistance at the drying stage.

Analysis of the results of measurements of air shrinkage shows that with an increase in the content of organo-mineral conglomerate mixed with rice husk, there is also a decrease in shrinkage on ceramic samples from 2.2 to 1.52 % (Fig. 7).

This is explained by the fact that amorphous silica appearing after firing rice husks contained in the conglomerate mixture stably structures the ceramic mass at the micro and macro levels at the molding stage.

It should be noted that with an increase in the amount of added rice husks up to 6 %, the thermal conductivity decreases from 0.50 to 0.27 W/(m·K) (Table 4). It should also be noted that with a decrease in the average density from 1,512 to 1,401 kg/cm^3 (Fig. 11), the water absorption index increases from 14 % to 17 % (Fig. 11).

With a decrease in the amount of introduced loess loam from 75 % to 72 %, the compressive strength decreases from 12.01 to 11.01 MPa. Thermal conductivity and water absorption are also reduced. In particular, the thermal conductivity of composition No. 5 was 0.27 W/(m·K) (Table 4, Fig. 9).

Analysis of the regularity of changes in physical and mechanical properties in the firing temperature range of 1,000 °C allows us to conclude the following:

– during the firing process, the organic part of the rice husk burns out, which is confirmed by a decrease in the average density of the samples;

– a favorable porous structure of the ceramic shard is formed due to the burning of rice husks and unburned ash particles, which helps to reduce the average density and thermal conductivity of the finished product.

It should be noted that composition No. 1 is considered the most acceptable. It includes 75 % loess loam, 22 % ash from a thermal power plant, and 2 % rice husk. The water absorption of the samples was 14 %. At the same time, the values of average density and thermal conductivity have a downward trend (Table 4, Fig. 11).

Analyzing the physicochemical processes occurring at a temperature of 1,000 °C allows us to conclude the following:

– at this firing temperature, the processes of solid- and liquid-phase sintering occur;

– in parallel, the combustion process of the organic part of the rice husk is completed, which is confirmed by the stabilization of the average density of the samples;

– the synergistic effect of ash and the resulting rice husk silica leads to the formation of a favorable porous and partially crystallized structure of a ceramic shard with improved physical and mechanical properties of the finished product (Fig. 12).

The complex use of rice husks and unburned ash particles from thermal power plants as a burnable additive reduces the average density and thermal conductivity of ceramic bricks, which confirms the experimental results (Table 4).

The effect of using solid waste from industry and agriculture in the production of wall materials is the creation of ceramic bricks with improved thermal characteristics. The method of utilization of agricultural waste through the use of large-tonnage waste from thermal power plants and rice processing waste – rice husk in the technology of wall materials is a specific example of solving the problem of ecology and environmental protection.

The limitation of the developed composition is the applicability of this ceramic brick as a structural thermal insulation material with low strength.

The disadvantage that should be considered is that the chemical and mineralogical compositions of raw materials for ceramics from different deposits are also different. This means that in each case, the developed composition should be adjusted empirically, preferably by applying mathematical planning of experiments using a rotatable plan for three variables.

The studied compositions for ceramic bricks are beneficial in terms of resource saving in conditions of shortage of excellent clay raw materials. Thus, the applied aspect of using the obtained scientific result is the possibility of using large-tonnage ash dumps and rice processing waste.

7. Conclusions

1. To perform experimental tasks, the main physical and chemical properties of raw materials for ceramic bricks, such as loess-like loam, ash from the Kyzylorda thermal power plant, and rice husk, were primarily investigated and determined. Thus, it was determined that the noted ash mainly consists of silica oxides ranging from 45 to 46.4 % and alumina ranging from 16.6 to 17.70 %. According to the content of Al_2O_3, loam belongs to the group of acidic raw materials, and according to fire resistance to fusible.

2. Depending on the method of using rice husk, a basic technological scheme for the manufacture of ceramic bricks with the use of ash from the Kyzylorda combined heat and power plant of the Republic of Kazakhstan was developed. The use of the rice husk itself in the crushed form in combination with ash gives a synergistic effect. The average density and thermal conductivity are reduced without a significant decrease in the strength of ceramic bricks.

3. By conducting experiments with 5 compositions, the raw material composition of ceramic bricks based on loess-like loams, rice husks, and ashes of the thermal power plant was selected. At the same time, the clay content ranges from 71 to 75 %, ash from the thermal power plant – from 18 to 22 %, and rice husk – from 2 to 6 % of the total mass of the charge composition.

4. In a series of experimental works, the ceramic specimens made according to the selected composition were subjected to welding and subsequent firing. Thus, it can be stated that the shrinkage of the ceramic sample during firing is in the range of 2.7–3.93 %. There is a decrease in the shrinkage of the molded ceramic raw material in the air from 2.2 to 1.52 %.

It was found that with an increase in the amount of rice husk to 6 % in the ceramic mass, the thermal conductivity decreases from 0.50 to 0.27 W/(m·K). The average density also decreases from 1,512 to 1,401 kg/cm^3. At the same time, the water absorption index is in the range of 14 % to 17 %. The strength is in the range of 11.01–12.01 MPa. The thermal conductivity of ceramic samples of various compositions is in the range of 0.27–0.52 W/(m·K).

Ceramic bricks made from a composition containing 75 % loess-like loam, 22 % CHP ash, and 2 % rice husk have a compressive strength of 14.01 MPa. Accordingly, the water absorption of these samples was 14 %, and the thermal conductivity was 0.52 W/(m·K).

Conflict of interest

The authors declare that they have no conflict of interest about this research, whether financial, personal, authorship, or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Data will be made available at reasonable request.

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