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Original Article

Influence of Oil Slurry on the Properties of Light Aggregates Based on Loams

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Abstract *- The paper presents an overview of recent studies on producing expanded clay (light aggregates) using various wastes, such as bitumen emulsions, oily waste, sewage sludge, and ash. Data on their use in reinforced concrete, expanded clay concrete, foam concrete, asphalt concrete, and even chicken feed are also provided. The results of the work show the efficiency of using waste in the production of high-quality aggregates. Various wastes in producing light aggregates are becoming relevant for research. Our work aims to use oil slurry as a corrective and bloating agent in producing light aggregates. The authors propose the following raw materials for producing light aggregates: loam, oil slurry, and fine-grained sand. The quality indicators of porous aggregates were determined by standard methods according to GOST 9758-2012. Sophisticated methods of research of raw materials and finished products were used. Compositions of ceramic combinations of aggregates and the technological parameters for producing light aggregates based on loams modified with oil slurry and fine-grained sand have been developed. The studied microstructure of the obtained material based on loam modified with oil slurry and sand allowed the conclusion that the introduction of oil slurry, which contains organic components in the form of resins, naphthenes, and paraffins, had a significant impact on the formation of the porous structure of fillers. The process of bloating of aggregates occurs due to the build-up of the liquid melt of the ceramic mass during firing when the reducing medium intensifies the process of accumulation of the liquid phase. It has been established that the oil slurry content in the composition of the developed compositions lowers the firing temperature by 50-100°C, and the sintering interval is more than 50°C. The resulting lightweight filler has high strength characteristics and low thermal conductivity.*

Keywords *- Expanded clay concrete, Filler, Fine-grained sand, Loam, Oil slurry, Thermal insulation.*

1. Introduction

Accumulation of waste from various industries is one of the global problems of developed countries. The construction industry consumes a huge amount of natural resources and is also responsible for significant energy use. It is expected that this will continue to happen with economic development when more people will need high-quality housing. Therefore, any building material that minimizes the use of natural resources or uses waste to a certain extent can have a promising future. In our opinion, oil slurry is a promising waste of industrial facilities. Annually, during the processing or transportation of oil, as a result of natural spills and accidents, more than 300 thousand tons of oil waste are generated, and the resources located in earthen storage are estimated at 5 million tons. This situation adversely affects the ecological situation, as these storage facilities increase the risk of animal death and air and groundwater pollution.

The production of building materials using waste could ensure a reduction in the cost and labor intensity of construction, in energy intensity and provide increased thermal protection of buildings. The reduction of available natural resources and the formation of waste have strongly impacted the environment. A rational solution is the production of artificial aggregates from waste, such as oil slurry.

Light aggregates are obtained by firing clay materials at a high temperature. The stocks of clay raw materials suitable for the production of aggregates are getting smaller every year, so it is necessary to find other types of raw materials to obtain high-quality products.

One of these clay materials is loams, available in almost every region. However, they relate to poorly bloating raw materials. For pore formation, oil slurry is used, which acts as a bloating agent and contributes to obtaining aggregates of the required quality.

The purpose of our work is to study the effect of oil slurry on the properties of light aggregates. To achieve this goal, the following objectives were set: to investigate raw materials, develop ceramic compositions of aggregates based on loam with the addition of oil slurry and fine-grained sand, to investigate the microstructures and properties of finished products.

Ledyaykin and Liaskin [1] and Poluboyarov et al. [2] investigated the physicochemical processes of obtaining materials from natural and man-made raw materials.

Andryukova and Yamanina [3] conducted studies of chemical, granulometric, and fractional compositions of large-tonnage oil and iron-containing production waste. The possibility of their use to prepare a bloating agent in the production of expanded clay has been established [3].

The works of Chernyshov and Tarasov [4] show the prospects for the development of expanded clay production with the addition of ashes and industrial waste and its use in works related to the construction and reconstruction of buildings and structures.

In the works of Bobkov & Klyavlina [5], the main regularities of obtaining expanded clay using sediment after water treatment facilities as a corrective additive were established.

Kazakh scientists Bishimbaev et al. [6] established the influence of bitumen emulsions on clays of various types. The organic part of the emulsions is adsorbed on the surface of clay particles. The presence of asphaltenes leads to effective hydrophobization of the particle surface with a further decrease in hydration and hardening of the system. The limits of bitumen concentration in water-bitumen emulsions from oil bitumen have also been established. It was shown that the viscosity increases due to an increase in contact interactions between the emulsion beads and with the predominance of cohesive interaction over the adhesive one as a result of gluing homogeneous surfaces [6].

Kwek et al. [7] perform scientific developments in producing light aggregates and concrete using industrial waste. A valuable area of research is dedicated to using a binder, a binary activator (silt), to obtain an artificial filler. The aggregate is used in concrete composition; its strength is more than 30 MPa, and its density is less than 2,000 kg/m3.

In the article, Alshannag et al. [8] performed experiments on using slag aggregate in reinforced concrete. The research results showed high strength characteristics of the products obtained.

Samokhvalov [9] investigated the process of firing light aggregates as one of the critical stages of production. A computational model of a software trajectory sensor for a multidimensional automatic control system for the technological process of firing expanded clay was developed. It allows for the smooth acceleration of furnace engines in starting and transient modes. It was established that using this sensor to control a rotating furnace significantly reduces currents and dynamic shocks in the drives and increases its reliability.

Borisov & Nazarov [10] presented a mathematical description of the process of forming expanded clay granules in a screw press as a controlled object. It was established that the use of methods of the theory of automatic control, system analysis, identification of controlled objects, and the theory of electric drive made it possible to find the dependencies that make up the mathematical description of the process of forming expanded clay granules in a screw press (controlled object).

A block diagram of a mathematical model was synthesized using the equations written in the Laplace images. Applying the obtained results will reduce the time spent designing modern automatic control systems to produce expanded clay and financial and material resources.

The quality of the obtained materials as the main indicator is described in the work of Yanovskaya and Gerekhanov [11]. The authors showed the features of examining the quality of expanded clay [11].

Light aggregates have a diverse scope of application: in expanded clay concrete [12], foam concrete [13], asphalt concrete [14], and even in chicken feed [15]. This indicates that the resulting lightweight filler is an environmentally friendly, cost-effective, and useful product.

To reduce energy costs during the firing of aggregates, scientists consider the possibility of using various installations and other equipment. They identify currently unsolved problems and outline ways to solve them [16, 17].

2. Materials and Methods

In this work, we considered light aggregates based on loams modified with oil sludge and with the addition of fine-grained sand from the West Kazakhstan region. The study was carried out in the educational and production center of the university.

The experiments were carried out on loam, fine-grained sand, and oil slurry of Western Kazakhstan.

First, we investigated the chemical properties of raw materials and obtained their thermograms, radiographs, and microstructures. Then, we investigated the rheological properties of oil slurry.

3. Results and Discussion

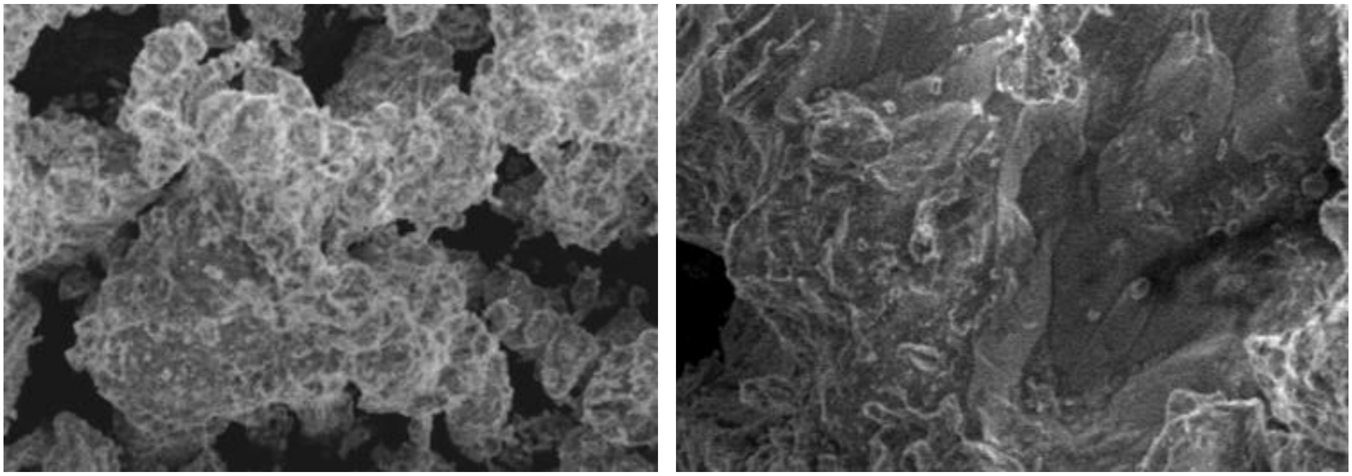

(a) (b)

Fig. 1 Microstructure of loam in various magnifications: a) x750; b) x1,000

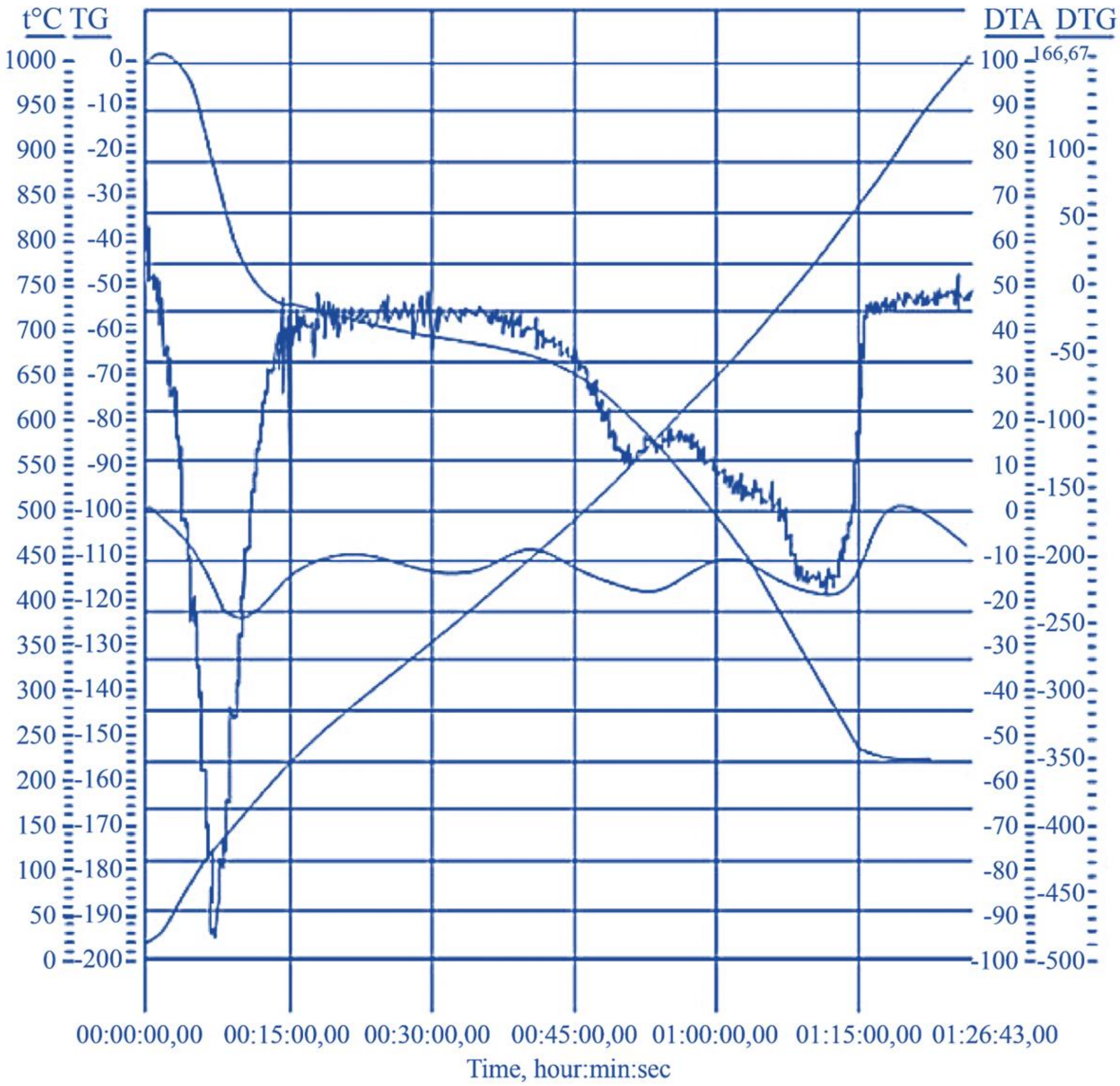


Fig. 2 A thermogram of a loam sample

Table 1. Chemical composition of loam of western kazakhstan

Name of Raw Material	Content of oxides wt.%												
	SiO_2	Al_2O_3	TiO_2	CaO	MgO	Fe_2O_3	P_2O_5	F	SO_3	CO_2	Na_2O	K_2O	Item
Chagansky Loam	52.2	15.1	-	12.3	2.9	7.1	-	-	2.4	-	-	2.2	10.9

The microstructure of the loam is porous, and the porosity reaches up to 50% (Fig. 1).

Table 1 shows the chemical composition of loam. According to the content of Al2O3, loam belongs to the group of acidic raw materials, and in terms of fire resistance, it is a low-melting substance. According to the content of Fe2O3, it belongs to raw materials with a high content of coloring oxides.

A thermogram of a loam sample is shown in Fig. 2. As can be seen from the figure, there are several distinct exothermic and endothermic effects on the curves of Differential Thermal Analysis (DTA) taken to a temperature of 1,000°C for loam. The endothermic effect is observed at temperatures 160°C, 420°C, and 830°C. The effect at 160°C is associated with the release of adsorption water; at 420°C it is associated with the removal of the main part of the constitutional water, and at 830°C the endothermic effect is associated with the decomposition of calcite and the release of carbon dioxide. At a temperature of more than 1,000°C, an endothermic effect is observed because the remaining part of the constitutional water of minerals, preserved at the firing temperature, is removed at the bloating temperature of 1,150°C, taking a direct part in the porosity of the ceramic mass. The exothermic effect at 260°C and 450°C is associated with the firing out of organic impurities. Another exothermic effect at 910°C is associated with the formation of high-temperature phases. On the TG curve at a temperature of 370°C, the inflexion point is visible, and on the DTG curve, it is seen that in the temperature range of 220°C and 470°C, a rather long peak is visible, indicating a low flow rate [18].

The calculation of the weight loss of a loess loam sample, according to the TG mg/min curve, is 12%; the correction factor of the DTG value is 0.002250 mg/min; the calculated final TG value is 156.27 mg; the minimum calculated by the DTG curve is 9.68541 mg/min.

Loam consists of a 12% montmorillonite component, which is present in the form of mixed formations with hydromica and kaolinite. The radiograph (Fig. 3) shows the reflexes of these minerals.

Of the crystalline phases, clay also contains the following minerals: quartz d/n=4.24; 3.34; 2.45; 2.28; 2.23; 2.12; 1.97; 1.81; 1.66; 1.53 Å, feldspar d/n= 3.18; 2.286; 1.534 Å, calcite d/n=3.02; 2.277; 2.08; 1.912 Å and hematite d/n=2.69; 1.83; 1.68; 1.59 Å.

X-ray Phase Analysis (XRPA) of fine-grained sand from the Bokeyordinsky deposit of the West Kazakhstan region (Fig. 4) showed that it contained the following minerals: silicon oxide d/n=4.24; 3.34; 2.45; 2.28; 2.231; 2.123; 1.975; 1.813; 1.668; 1.656; 1.539 Å, feldspar d/n=3.45; 3.22; 3.02; 2.44; 1.80; 1.52 Å, calcium carbonate d/n=3.02; 2.49; 2.27; 1.86; 1.52 Å.

The microstructure of fine-grained sand is shown in Fig. 5.

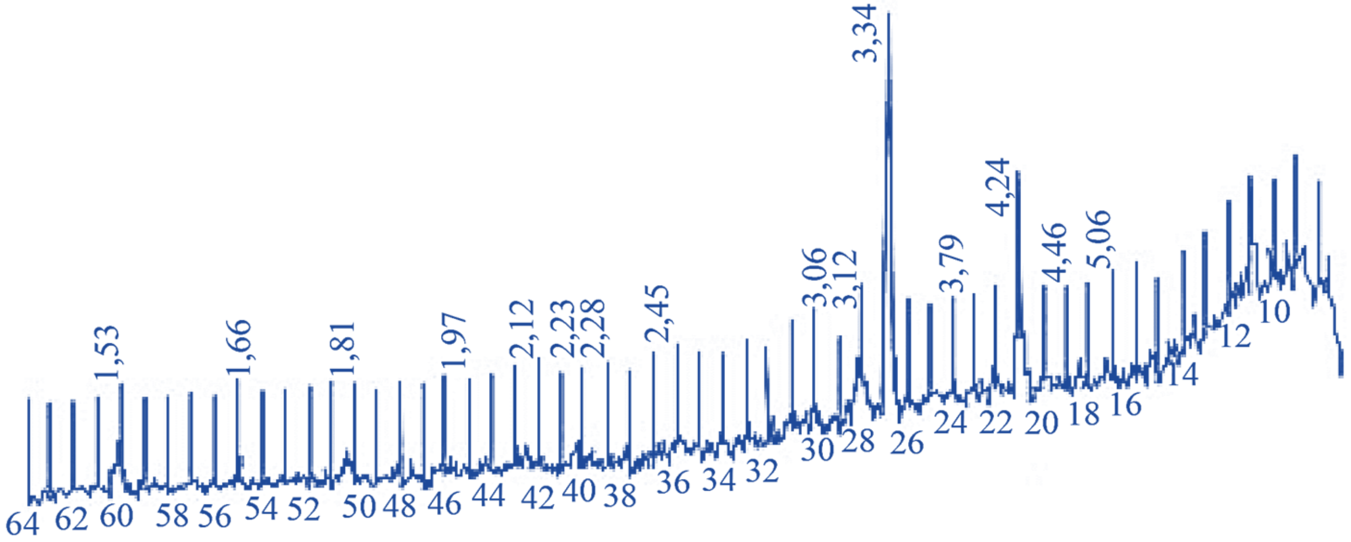


Fig. 3 Radiograph of loam

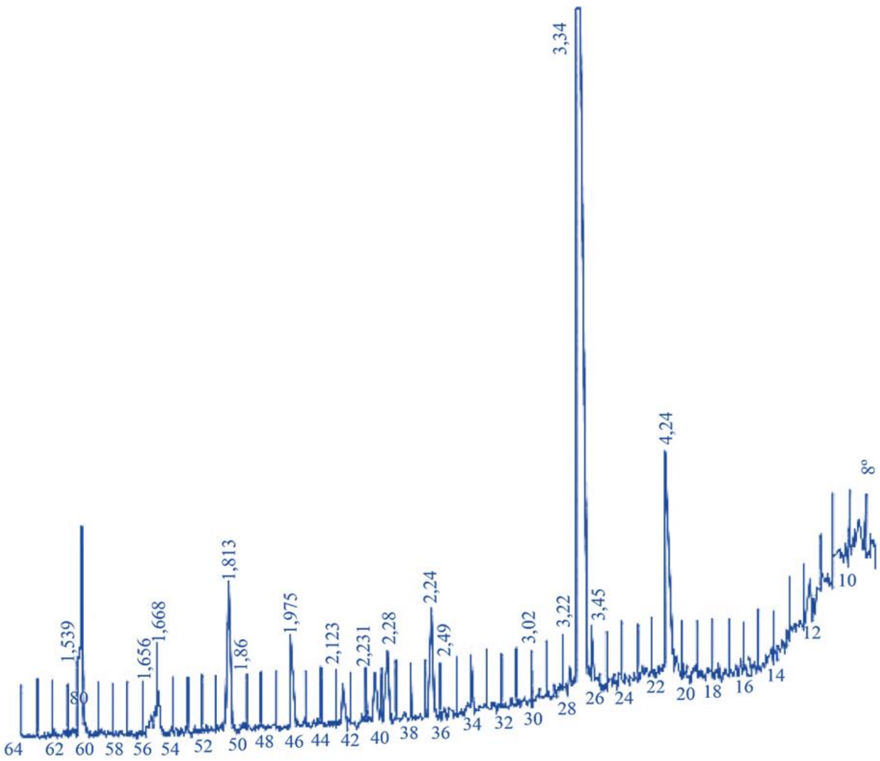
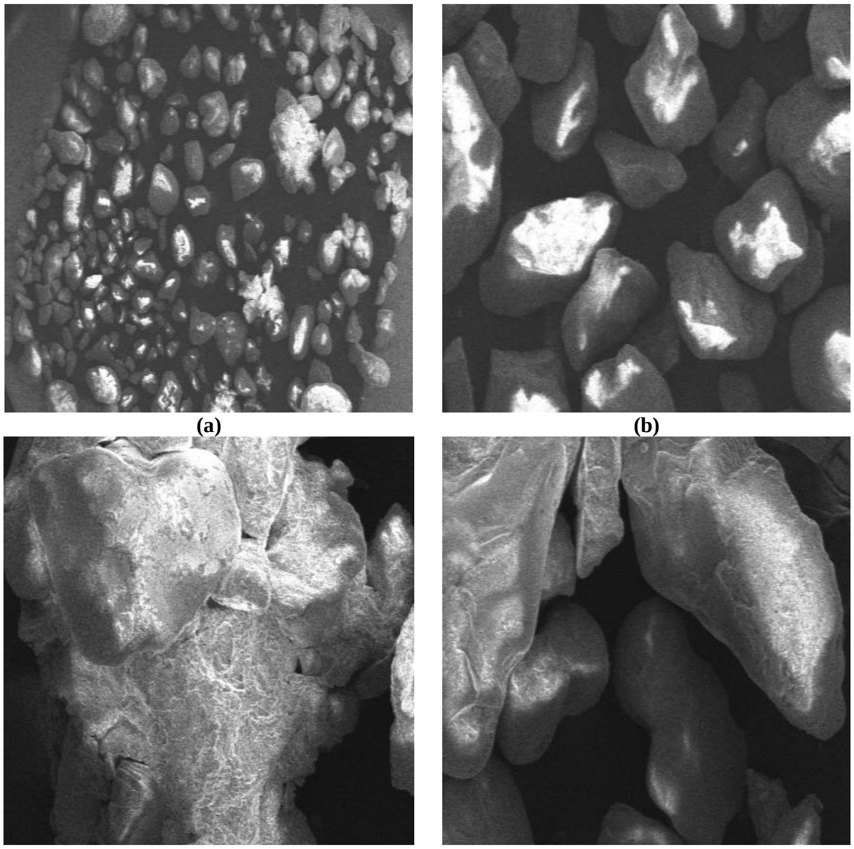


Fig. 4 Radiograph of fine-grained sand



(a) **(b)**

(c) **(d)**

Fig. 5 Microstructures of fine-grained sand in magnifications: a) x 17; b) x 95; c) x 110; d) 130

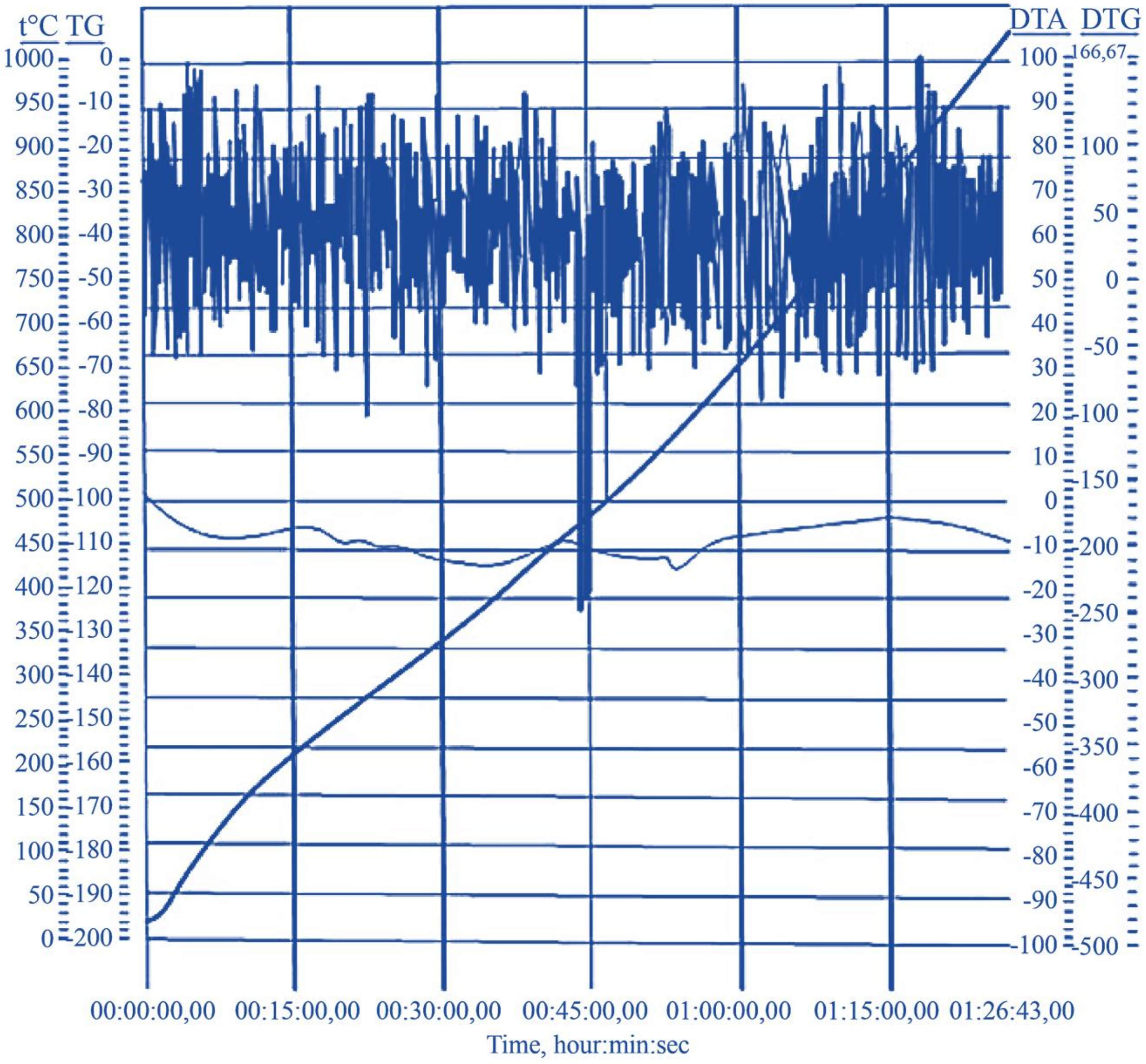


Fig. 6 Thermogram of a sample of fine-grained sand from the Bokeyordinsky deposit

On the DTA curves (Fig. 6) of sand, weight losses are practically not observed.

The calculation of the weight loss of a loessial loam sample, according to the TG mg/min curve, is 12%; the correction factor of the DTG value is 0.002250 mg/min; the calculated final TG value is 156.27 mg; the minimum calculated by the DTG curve is 9.68541 mg/min. Endothermic effects on the DTA curves are observed at temperatures of 130°C, 360°C, and 575°C; they are associated with removing free and chemically bound water. A slight exothermic effect is observed at a temperature of 475°C, characterized by the presence of orthoclase. At 875°C, is an exo-effect associated with the decomposition of calcite. At temperatures above 1,000°C, the formation of high-temperature phases is noted [18].

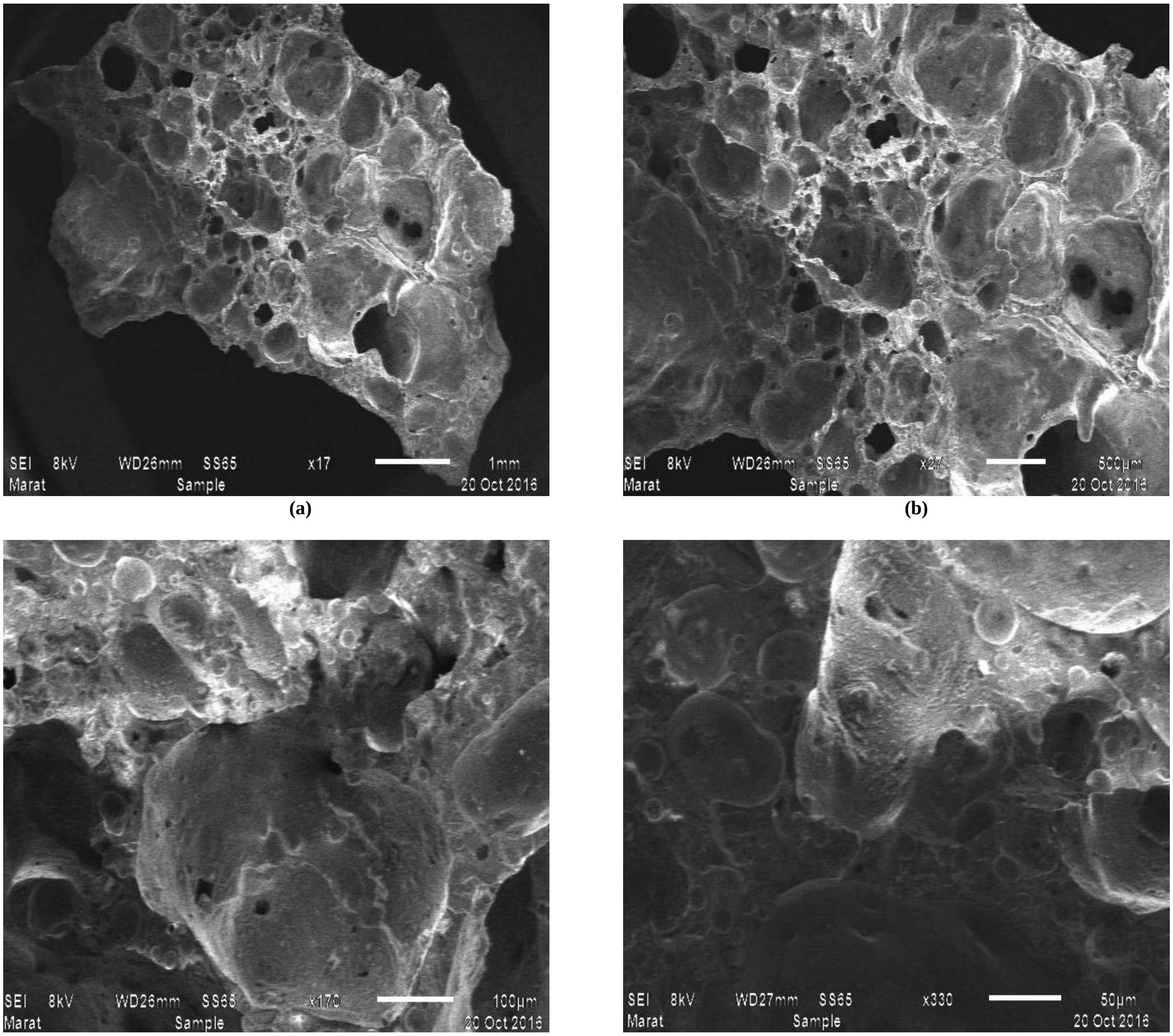
Oil slurry consists of an oil product (48.6%), water (35.9%), and mechanical impurities (the rest). We established that there are paraffin-naphthenic hydrocarbons and resins in the composition of oil slurry. The results of studies of the rheological properties of oil slurry are shown in Table 2.

Table 2. Rheological properties of oil sludge

Name of the Indicator	Density, kg/m^3 at 20°C	Mass Fraction of Sulfur, %	The Heat of Combustion, kJ/g	The Content of Chloride Salts, mg/dm^3
Values	840-845	0.034	48.9	29.3

Table 3. Physical and mechanical properties

Compositions	Bulk Density, kg/m^3	Compression Strength in the Cylinder, MPa	Thermal Conductivity, W/m·K	Water Absorption, %	Bloating Coefficient, W/m*K
1	660	4.2	0.21	17.2	1.8
2	640	4.3	0.17	17	2.5
3	635	4.4	0.17	16.2	2.6
4	640	5.9	0.17	16.3	2.64
5	642	5.95	0.17	17	2.2



(a) (b) (c) (d)

Fig. 7 Microstructure of filler based on loam modified with oil slurry and sand: a) x 17; b) x 27; c) x 170; d) x 330

Initially, loam was broken in a laboratory ball mill to a specific surface of 1,500 to 2,000 cm2/g. Then, the loam, sand, and oil slurry were thoroughly mixed until a homogeneous mass was obtained. To compose the ceramic composition, the following compositions of fillers were developed:

1st composition: 95% loam, 1% oil slurry, 4% sand.
2nd composition: 90% loam, 2% oil slurry, 8% sand.
3rd composition: 85% loam, 3% oil slurry, 12% sand.
4th composition: 80% loam, 4% oil slurry, 16% sand.
5th composition: 75% loam, 5% oil slurry, 20% sand.

A ceramic mass with a molding humidity of 20-25% was prepared from the studied compositions. Then, granules were formed and heat-treated at 350°C for an hour. After that, the firing was carried out in a laboratory firing furnace at a firing temperature of 1,150 20°C for 5-7 minutes. Next, the granules were cooled and tested to determine the physicomechanical properties of the resulting filler (Table 3).

The bulk density of compositions No. 2, 3, 4, and 5 during firing practically does not depend on the change in composition. The decrease in density occurs mainly due to removing residual moisture, including hydrated water from loams, and the firing of organic materials as the amount of oil slurry increases.

In composition No. 4, there is an increase in bulk density, but with it, the strength of expanded clay increases. In composition No. 5, the bloating coefficient decreases to 2.2, which does not comply with regulatory documents.

The thermal conductivity coefficient of compositions No. 2, 3, 4, and 5 is 0.17 W/m*K. The optimal composition is composition No. 4.

Fig. 7 shows the microstructures of expanded clay based on loam modified with oil slurry and sand in various magnifications.

As seen from Fig. 7, the appearance of the pores is mostly rounded. The pore distribution in the filler sample is almost uniform over the volume of the material. Large pores are communicating. The marginal zone of the granules has a dense crust, which positively affects their water absorption and the strength of the filler. The surface of the granules is rough, which contributes to better adhesion in the concrete composition.

Thus, microscopic studies of the overall structure of the samples, including the structure and characteristics of the pores, show that the structure of the samples is cellular, the distribution of pores is almost uniform, and the marginal zones of the samples have a dense impermeable crust, which helps to reduce water absorption. Their rough surface contributes to better adhesion of aggregates with components that make up the concrete.

For a detailed study of the neoplasms that resulted from the firing of a light aggregate, an XRPA was performed (Fig. 8).

The filler sample (composition No. 4) contains silicon oxide d/n: 4.24; 3.34; 2.45; 2.28; 2.23; 2.12; 1.97; 1.81; 1.66; 1.53 Å; feldspar d/n: 3.18; 2.28; 1.53 Å; montmorillonite d/n: 5.06; 4.46; 3.79; 3.06; 2.45; 2.28; 2.12; 1.97; 1.81; 1.67 Å.

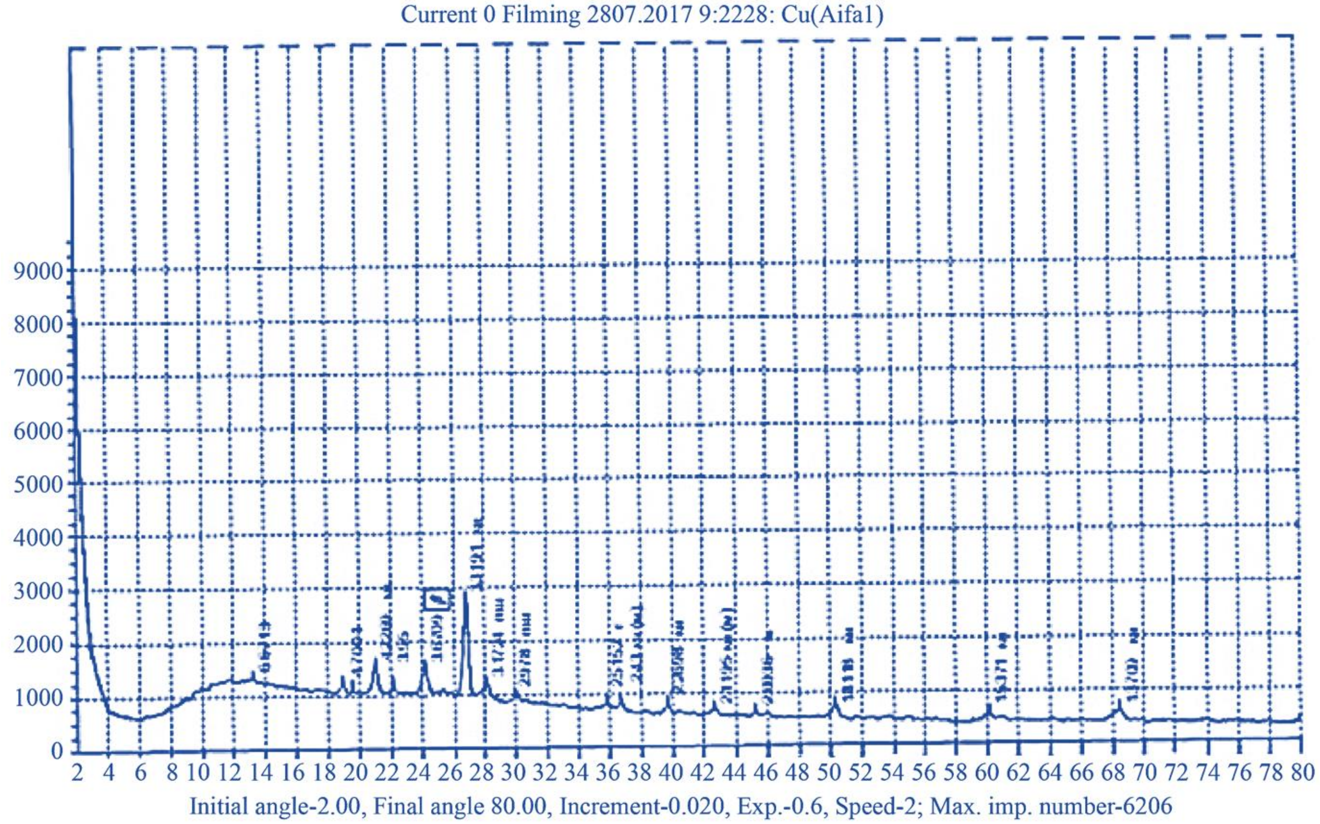


Fig. 8 XRPA results of a sample of a light aggregate based on loam modified with oil slurry and fine-grained sand

According to the results of the XRPA, the sample contains quartz and feldspar. It should be noted that the feldspar components were modified into anorthite as a result of firing since their peaks practically coincide.

The test sample contains mullite (M), d /n: 2.43, 2.1195, 2.0036 Å, which indicates the modification of the components. This applies primarily to minerals such as kaolinite, calcite, and hydromica as a result of firing. No iron oxides indicate their interaction with other components or transition to an amorphous state. The amorphousness of the sample under consideration is reduced. The content of SiO2 in the sand was high. Reacting with Al2O3 particles forms mullite and, thus, improves the plasticity of ceramic masses, while feldspar contributes to a decrease in the firing temperature.

Oil slurry is used as a pore-forming and bloating agent. This is due to the presence of a large number of aromatics and unsaturated hydrocarbons in the organic part of the oil slurry. Fine-grained sand is used in the ceramic mass as a strengthening additive in producing light aggregates [18].

The use of oil slurry and sand reduces fuel and energy costs by 30-40% due to the complete burnout of oil slurry in the ceramic mass; a porous and durable structure of the finished product is created due to the bloating effect of oil slurry and the structural features of fine-grained sand.

The results of our study, as well as the results of research by such scientists as Shi Ying Kwek et al. [7], showed that in the production of light aggregates using industrial waste, the resulting aggregate, fired at a temperature of 1,150 ± 20°C, had high strength, and could be used in light concrete. Similar results were obtained by Spanish scientists Moreno-Maroto and co-authors [19], who obtained light aggregates from olive pomace waste, the high calorific value of which helped significantly reduce the firing temperature and obtain a filler with high strength indicators. In our studies, oil slurry acted as a calorific and pore-forming component.

4. Conclusion

We established a special relevance of the study on the use of oil slurry as a modifying component in the technology of production of light aggregates based on loams. Based on the study of raw materials' physicomechanical and chemical-mineralogical properties, a ceramic composition based on loams was proposed to create a resource- and energy-efficient technology of light aggregates using oil slurry and fine-grained sand. We found that the addition of oil slurry and fine-grained sand to ceramic masses makes it possible to improve the molding properties due to the content of naphthenic-paraffin and resinous components in the oil slurry, which makes it possible to facilitate the operation of mixers and obtain granules without cracks, as well as to increase the strength indicators of aggregates by including fine-grained sand.

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