Technology of the porous granular material out of thermal power engineering waste

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Abstract. The article presents the results of resource-saving technology development of porous granular material. Research is devoted to the development of scientific ideas about highly porous structures formation. The research objective is to develop a low-energy technology for producing porous granules based on the multiple use of thermal power engineering waste. Research novelty lies in conformity with a principle of combined porous structure's formation of granules during thermal swelling of molding sand based on technogenic materials. Mixture of liquid sodium glass, fly ash and ash aluminosilicate microsphere has been developed to obtain the granules. Techniques for granulating liquid glass mixture have been developed. The parameters for thermal treatment of granules have been established to ensure formation of a strong, porous, and water-resistant structure. Physicomechanical and thermal properties of porous granules fired at a temperature of 350^{0}C were studied. Microstructure of the fired granules was studied; their porosity is of 78 – 80%, bulk density is 210 – 230 kg/m^3, and the thermal conductivity coefficient is 0.084 – 0.085 W/(m·^{0}C). There has been developed a technological scheme for production of a granular material based on finely dispersed thermal power engineering waste. Comparative analysis of characteristics of the developed material and expanded clay was carried out.

1 Introduction

A significant part of electrical energy is generated by thermal stations due to sequential conversion of one type of energy into another. Thermal power plants (TPP) are consumers of solid fuel. Fuel coals contain non-combustible mineral impurities. Mineral part of the fuel is represented mainly by a mixture of clay or marlaceous substances with sand, as well as minerals containing iron, aluminum, calcium, magnesium and other elements. Solid fuel combustion occurs at a temperature of 1200 – 1400^{0}C in the oxidizing environment. Physical and chemical transformations occur in the mineral part of fuel, and various compounds are formed when exposed to heat. The use of coal in thermal power engineering inevitably leads to large-tonnage waste formation; their dumps occupy large areas, and they are a source of environmental pollution and pose an environmental problem.

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Ash and slag waste is represented by fuel lump and granulated slag, by ash and slag mass (wet poly disperse mixture out of dumps); fly ash (dry powder) and sludge ash (hydraulic slurry).

Characteristics of chemical, material and dispersed composition of thermal power engineering waste predetermined wide possibilities for the use of TPP ashes and slag in the construction industry [1–5]. The feasibility and efficiency of using thermal power engineering waste in building materials' technology is confirmed by numerous developments [6–11].

Along with the achievements in rational disposal of ash and slag waste, there are unique properties of thermal power engineering waste which remain unrealized in highly porous building materials technology. Energy-efficient construction requires durable materials for thermal insulation of objects.

The objective of the study is low-energy technology development for producing porous granules based on multiple use of thermal power engineering waste.

The working hypothesis is creation of a highly porous structure for granular material by combining hollow coal waste.

The research object is porous granules obtained by heat treatment of molding sand made out of thermal power engineering waste.

2 Materials and methods of research

Finely dispersed hollow thermal power engineering waste such as fly ash and ash aluminosilicate microsphere was used as raw materials. The choice of waste is due to the high dispersion of materials, the possibility of creating homogeneous structures, low density, increased resistance to thermal influence and aggressive environment. Liquid glass was used to bind particles of man-made components together.

TTP fly ash is powdery mass consisting of melted round particles with a size of 60 – 200 microns. Spherical structure of fly ash particles is due to the short-term presence of coal in the high temperature zone. As a result of intense increase in temperature, the burning out of organic substances of coal and mineral part sintering occur almost simultaneously. The gas phase released in this case swells the melt. Under shock chilling the melted particles of pulverized ash are formed, having tiny closed pores. Fly ash consists of aluminosilicate opaque glass and contains particles of quartz, mullite, and unburned coal. TPPs fly ash is characterized by a specific surface area of 300 m^2/kg and has a bulk density of 720 kg/m^3.

Aluminosilicate microsphere is a fraction of fuel ash that is formed during high-temperature flaring of coal. Ash microsphere consists of glass-crystalline hollow spherical particles with a diameter of 50 – 200 microns, and has a bulk density of 400 kg/m^3.

Liquid sodium glass is aqueous solution of sodium silicate ($Na_2O \cdot n\ SiO_2 + m \cdot H_2O$), characterized by a silicate module n = $SiO_2:Na_2O$ = 2.7 and a density of 1350 kg/m^3. Liquid glass exhibits high adhesion to most materials, which contributes to the gluing of dispersed particles of a technogenic component. In addition, liquid glass affects rheological properties of molding mixture and increases granules porosity due to thin-walled cells that are formed during thermal bloating.

Chemical composition of molding sand's components is given in Table 1.

A molding mixture, consisting of the following components, wt.%: TPP ash – 20; ash aluminosilicate microsphere – 30; liquid sodium glass – 50 was used to obtain granular material [12].

Table 1. Chemical composition of raw materials.

Name of material	Content, wt.%							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	loss on ignition
Fly ash	48.5	17.8	1.4	14.8	3.3	1.3	2.6	10.3
Ash aluminosilicate microsphere	68.3	25.5	1.5	2.2	1.5	0.3	0.7	–
Liquid glass	28.9	0.1	0.1	0.2	–	10.7	–	60.0

Dosing of bulk materials was carried out by mass, and it was carried out by volume for liquid glass. Thermal power plant ash and ash aluminosilicate microsphere in the given ratio were mixed in IKARW-20 overhead mixer with a rotation speed of 500 rpm.

The granules were formed on a drum granulator, the rotation speed of which was 250 – 300 rpm. A thoroughly mixed mixture of dry components was loaded into the drum granulator, where liquid glass was introduced by irrigation. Duration of pelletization was 5 – 10 minutes in the granulator, taking into account granules diameter.

The strength of molded (raw) granules was assessed by crushing load using a modified Vicat apparatus. The breaking load corresponded to the mass of the load at which cracks formed in the granule. The crush test was carried out on pellets with an average diameter of 10 mm. The crushing strength of the granules was 15.7 N/grain based on the results of 15 tests. The granules, when dropped from a height of 300 mm, withstood at least 12 falls.

Molded granules with an average density of 970 – 985 kg/m^3 were poured onto pallets in a layer of 10 – 15 mm and loaded into a LOIP LF drying oven and subjected to heat treatment at a temperature of 300 – 350^{0}C. Temperature rise rate was 100 – 120^{0}C/h, isothermal holding time – 40 minutes. After heat treatment, the granules were removed from the installation and subjected to physical and mechanical tests. Standard methods for testing porous inorganic aggregates for lightweight concrete, as well as methods generally accepted in research practice were used to determine the basic properties of the porous granular material.

3 Results

The results of physical and mechanical tests of porous granules are given in Table 2.

The total porosity of the fired granules was calculated taking into account the true density of the granule substance and the average density of the granules.

Formation of pores in the granules under study occurs with the participation of liquid glass and due to particles of thermal power engineering. Swelling of the molding sand due to liquid glass provides the granules with the correct spherical shape (Figure 1). In this case, the volume of granules increases by 1.18 – 1.20 times.

The microstructure study was carried out on the surface of the split granules. Splitting of granules is accompanied by destruction of hollow particles, which indicates high adhesion of the liquid glass substance to the technogenic filler. Hollow particles of aluminosilicate microspheres and thermal power plant ash are a carrier of porosity, ensure the stability of expanded granules structure, and perform a frame-forming function. A significant part of the pore space of granules is formed from isolated volumes of hollow particles of aluminosilicate microspheres. Particles of aluminosilicate microsphere form the basis of the contact structure. The other part of the pores is formed in the liquid glass mass filled with TPP ash and is represented by closed cells, the average size of which is 1 – 10 microns (Figure 2). The cellular liquid glass mass envelops and holds together the particles of technogenic filler and fills the space between them.

The granules have voids of 10 – 100 µm in length and they are not filled with substance. The volume of voids averages 10 – 20%. Water absorption of granules is mainly due to the presence of voids.

The strength of fired granules was determined by the splitting method. The splitting strength of each granule was calculated taking into account the maximum splitting force and the splitting area of the granule.

The splitting strength of granules was determined as the arithmetic mean value of the results of 10 tests on a hydraulic compact press PGM-1000MG4.

Water absorption of granules was determined taking into account initial sample's mass and the mass of the sample saturated with water for 1 hour.

The softening coefficient is a value calculated as the ratio of the strength of granules saturated with water for 1 day to the strength of dry granules. Heat treatment ensures formation of a porous, water-resistant structure of liquid glass granular material.

The thermal conductivity coefficient of granular material was determined using an ITP-MG4 thermal conductivity meter on paraffin samples measuring 100x100x10 mm with the porous granules evenly distributed.

The experimental results form the basis for development of a technology for porous granular material production (Figure 3), which includes the following stages: delivery and storage of raw materials; preparation of molding mass; granulation; bloating during heat treatment; fractionation.

Table 2. Basic properties of porous granular material.

Properties	Values
Average density of an individual granule, kg/m^3	420 – 430
Bulk density, kg/m^3	210 – 220
Granule porosity, %	78 – 80
Splitting strength, MPa	2.6 – 2.8
Compressive strength in a cylinder, MPa	1.2 – 1.3
Water absorption,%	7.5 – 8.3
Softening coefficient	0.87 – 0.88
Thermal conductivity coefficient, W/(m·^{0}C)	0.084 – 0.085

Fig. 1. Appearance of fired granules.

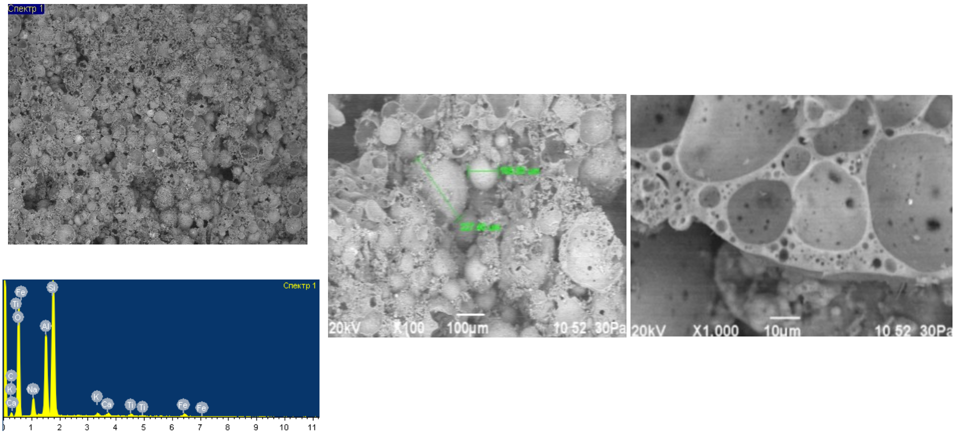

Fig. 2. Microstructure of porous granules.

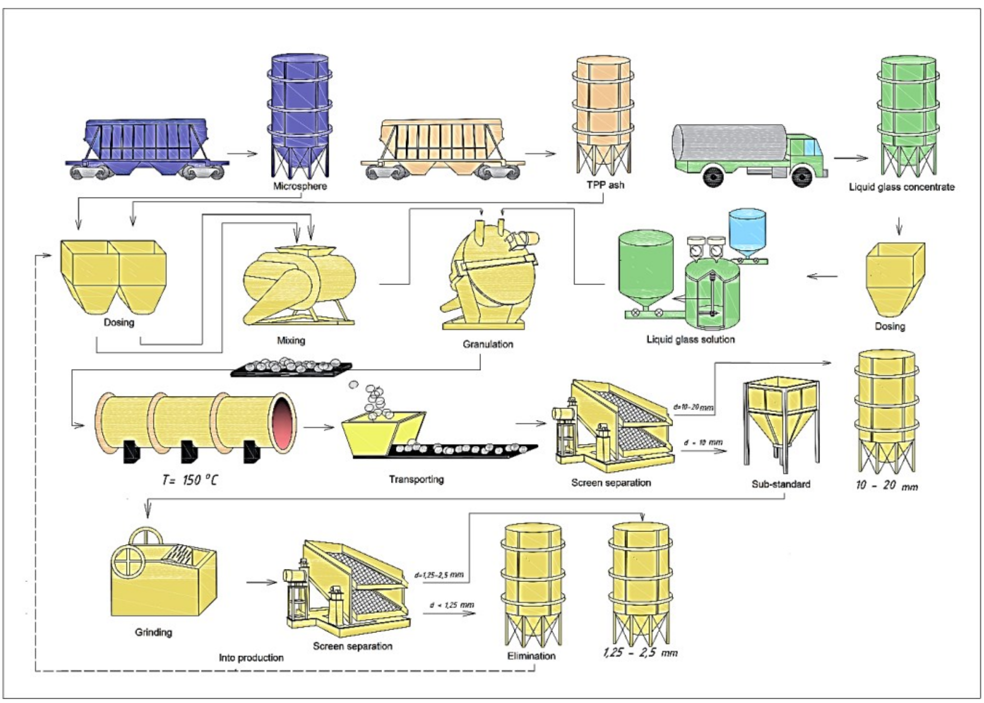

Fig. 3. Process flow diagram for the production of porous granular aggregate.

Raw materials (TPP ash, ash aluminosilicate microsphere and liquid glass concentrate) are stored in metal silos to maintain the required characteristics.

To prepare a solution of liquid glass, use water heated to a temperature of 30 – 50^{0}C. Liquid glass concentrate is added to a turbulent mixer with heated water, mixed thoroughly until a viscous state is obtained and the uniform consistency is obtained for 30 – 40 minutes. Dry components (TPP ash, ash aluminosilicate microsphere) are mixed in a twin-shaft mixer for 60 – 70 s. The finished mixture of dry components is sent for granulation. Liquid glass is fed directly into the granulator.

Raw granules molding is carried out in a disc granulator. Dry mixture is continuously fed into the rotating bowl, which, due to the sprayed liquid glass, pellets turn into the round granules. The granulation process includes two stages: the first is moistening the mixture with a liquid glass binder to moisture content of 40 – 70% of the optimal value; the second is granulation, which is carried out at a speed exceeding the critical speed of rotation of the plate. As they move in the bowl, the granules increase in diameter and exit the granulator through the discharge hole into a special tray, from where they are transferred to a conveyor belt. The duration of the granulation process is 10 – 15 minutes.

The expansion of granules is carried out during heat treatment in drum dryers at a temperature of 350^0C. The duration of heat treatment is 40 – 50 minutes. The expanded granules are sent to vibrating screens for classification into fractions.

During heat treatment, external and internal deformations of the granules are possible, which are subsequently screened out and rejected. It is advisable to utilize rejected granules for processing into porous sand; substandard granules are crushed, and the crushed mass is sent for screening. Screenings formed during separation of sand fractions are returned into production. The resulting fractions of porous granules and crushed sand are sent by pneumatic transport to the finished product warehouse.

Granular material with a porous structure is intended for use as porous aggregate for lightweight concrete and thermal insulation backfill.

4 Discussion

The low firing temperature of the developed granular material reduces energy costs by almost 7 times compared to expanded clay technology as common porous aggregate. Reduced processing costs make it possible to compensate for the increased costs of raw materials for producing granules out of liquid glass sand.

When using the developed granular material as insulation, a smaller volume of thermal insulation backfill will be required. The thermal conductivity indicators of expanded clay and the developed granular material correlate as 0.125:0.085 = 1.47 (Table 3).

Table 3. Comparative characteristics of porous materials.

Characteristic	Developed granular material	Expanded clay
Grain fraction, mm	10 – 15	10 –15
Bulk density, kg/m^3	220	400
Thermal conductivity coefficient, W/(m·^{0}C)	0.085	0.125

This means that a layer of the developed material with a thickness of 10 cm is similar in thermal conductivity to a layer of expanded clay with a thickness of 14.7 cm. To ensure equal thermal conductivity of the compared thermal insulation backfills, the consumption of expanded clay will be 1.47 times higher than the consumption of the developed material. When using the developed granular material as insulation, the economic effect will be obtained by reducing the need for thermal insulation material. According to preliminary calculations, the cost reduction when using porous liquid glass granules compared to expanded clay will be 30%.

5 Conclusions

A technology for producing highly porous granular material based on ash waste generated during coal combustion at thermal power plants has been developed.

Technology of the developed porous granular material involves the use of man-made waste from thermal power engineering, which does not require preliminary preparation; it implements low-temperature processes for processing raw materials. This ensures the resource-saving aspect of the developed technology.

Advantages of using porous granular material are determined by its high heat-shielding properties, rigid structure, resistant to environmental influence. The use of granular thermal insulation material will reduce energy consumption during the operation of construction projects.

Calculations of economic indicators confirmed effectiveness of porous granules and feasibility of their use in construction.

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