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Research Article

AN ARTIFICIAL POROUS GRAVEL BASED ON SLAGS OF THERMAL POWER STATIONS

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ABSTRACT

The paper is concerned with the obtaining of a qualitatively new artificial porous gravel from slags or ash-slag mixtures of thermal power stations. The developed technology makes it possible to broaden raw stuff basis of production of artificial porous aggregates for lightweight concretes, allows resolving the problem of utilization of secondary resources in the manufacturing of building materials and of environment protection from pollution.

On the strength of the investigation results a technology of obtaining porous gravel or ash-slag mixtures of thermal power station has been developed. The main physical-mechanical characteristics of the obtained aggregate are studied. It has been revealed that by its physical-mechanical properties the obtained artificial porous aggregate complies with the requirements of the acting standard. It has been found out that heat insulating, heat insulating constructional and structural lightweight concretes for space enclosing and load-carrying constructionsobtainedbased on it.

INTRODUCTION

A decrease in material consumption of building structures, rise in their load-carrying capacities, increase in their heat-insulating properties, reduction in mass of buildings and structures are the most important problems of construction.

One of the most efficient ways of resolving these problems is the manufacture and use of products and structures made of lightweight concretes on the base of artificial porous aggregates [1, 2, 3, 4, 5].

Nowadays, the most widespread artificial porous aggregate is keramzit (expanded clay aggregate) made of natural argillaceous raw stuff. However, well-expanding argillaceous raw stuff for producing keramzit gravel is available in far from all regions and their stores are diminishing with every year. The majority of plants for its production use low-quality raw stuff and improve batch compositions through introducing various additives in it. For this reason the use of industrial waste, in particular, slags of thermal power stations as the essential raw material for manufacturing artificial porous aggregates is acquiring importance [6, 7, 8, 9, 10].

The utilization of industrial waste in the production of artificial porous aggregates permits to save material as well as natural resources, to resolve the problem of employing secondary resources in the manufacturing of building materials to some or other extent and of protecting the environment from pollution [11, 12, 13].

Materials

In the process of deciding on the suitability of slags of thermal power stations as the main raw stuff for artificial porous aggregate production, were explored slags of diverse plants differing from one another by origin and chemical compositions. Table 1 shows chemical properties and places of origin of various fuel slags. In making raw granules different binding and gas-generating additives were used apart from fuel slags.

Analysis of results related to exploring chemical compositions of the fuel slags demonstrates that activity modulus and basicity modulus of the slags presented in Table 1 do not differ much between each other.

Basicity modulus varies in the range from 0.04 to 0.25, activity modulus fluctuates between 0.30 and 0.51. There exists a marked difference in calcination losses in chemical composition of the slags which can be the chief parameter

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when a gaseous phase is formed under the action of high temperatures.

Table 1 Chemical compositions of granulated fuel slags

No	Name of a plant	Chemical composition, %									Basicity modulus	Activity modulus
		SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	SO_3	Na_2O+K_2O	calci-nation losses		
1	St. Petersburg TPS-5	60,4	22,8	-	8,96	4,08	2,82	0,87	3,05	0,8	0,07	0,38
2	Tom-Usinsk TPS	58,09	29,69	0,26	7.01	3,11	0.94	0.21	2,85	-	0,04	0,51
3	VoronezhTPS	51,22	19,91	11,38	1,75	8,13	1,76	0,45	3,36	5,54	0,12	0,38
4	Krasnoyarsk TPS-1	56,2	17,2	9,21	1,78	12,3	6,5	0,85	2,75	4,68	0,25	0,30

Calcination losses in chemical composition of Voronezh thermal power station slags are 5.543% and are only 0.8% in that of St. Peterburg thermal power station-5 slags. Calcination losses are absent in Tom-Usinsk thermal power station slags.
The rest of constituent oxides in diverse slags do not differ so strongly from one another. The slags contain sufficient quantity of Fe_2O_3 and FeO as well as Na_2O+K_2Owhich play a significant part in expansion under the effect of high temperatures and in the process of liquid phase formation in the mass. Bulk density of the fuel slags varies within the limits from 1150 to 1300kg/cu.m. The size of the main part of the fraction is less than 10.0 mm [14].

Experimental Procedure

Various fuel slags and correcting additives were employed as the basic raw stuff in the performance of experimental investigations. When creating a batch composition plastic clays were taken as binding additives and mineral, organic or organo-mineral additives were chosen as gas-generating ones.

In the course of investigations on studying expansion kinetics of a mass based on granulated fuel slags specimens in the shape of small cylinders of 16 mm in height and diameter as well as granules of 5-10mm in diameter were made from a specially prepared batch using binding and gas-generating additives on a laboratory plate granulator.

The experimental investigations were conducted in three stages: batch preparation and raw granules making at the first stage, study of mass expansion kinetics and aggregate structure formation at the second stage, study ofpetrography and exploration of physico-mechanical properties of an artificial porous aggregate being obtained at the third stage. In performing these experimental investigations X-ray (diffraction), differential thermal and petrographic analyses were used.

Semi-production tests and specification of process parameters of porous gravel manufacture were carried out on a process line of the Research and Design Institute of Building Materials named after S.A.Dadashov.

Analytical Investigation

One of the principal requirements for poreformation of the masses under study is primary structure of crystalline phases in starting materials. Therefore, glass content was determined in all investigated slags. X-ray analyses demonstrate that the cooling in all employed slags took place under normal enough conditions, degree of crystallization is almost absent. The basic constituent on the X-ray photograph of thermal power station slags is glass (Fig. 1).

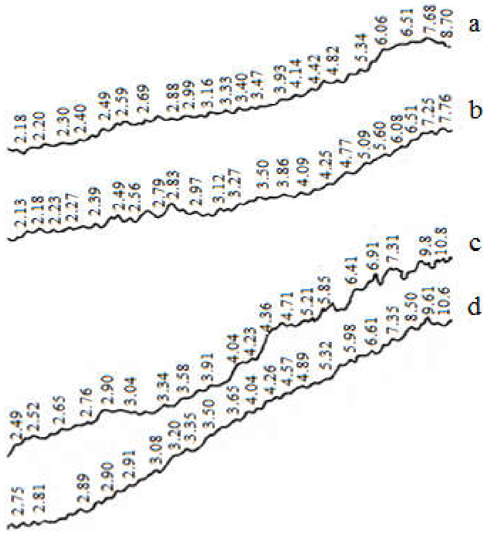

Fig 1 X-ray analyses of granulated fuel slags

a–granulated slags of St. Petersburg TPS-5;
b–granulated slags of Tom-Usinsk TPS;
c–granulated slags ofVoronezh TPS;
d–granulated slags of Krasnoyarsk TPS-1.

Table 1 contains the results of investigations into expansion of a mass based on thermal power station slags and variations of density and strength of the expanded specimens.

The investigation results reveal that processes of mass pore formation and development of the aggregate porous structure are significantly influenced by their expansion conditions. The primary porous structure arises during granulation of dispersed batch. The density of raw granules is 1.60-1.62g/cu.cm.

A considerable part of pores formed in this period is observed in granules during their thermal treatment. It is seen from table 2 that under the action of high temperatures up to 850^0C individual grains begin to soften, sinter and, eventually, compact. Gas-impermeable closed cavities are formed which are in pyroplastic state, i.e. they can undergo plastic deformations without continuity break. The density in this case attains 1.68…1.72g/cu.cm. Withrise in expansion temperature up to 950^0C gases evolve within cavity due to gaseous phase formation and these gases having no escape through shell, create excessive pressure in the interior cavity under the action of which granules being softened start expanding. A decrease in density of the expanded granules is detected. The process of expansion goes on before a temperature of 1050…1150^0C. The density of the expanded granules drops to 1.38…1.40g/cu.cm.

Table 2 Change in density of expanded specimens made from various slags ofthermal power stations depending on expansion temperature

No	Name of fuel slags	Expansion temperature, ^0C				
		850	950	1050	1150	1200
		Density, g/cu.cm				
1	Slags of Voronezh TPS	1,68 1,62	1,48 0,95	1,38 0,42	1,40 0,35	1,45 0,42
2	Slags of Krasnoyarsk TPS-1	1,67 1,64	1,54 1,12	1,42 0,56	1,38 0,35	1,46 0,44
3	Slags of St. Petersburg TPS-5	1,70 1,68	1,52 1,05	1,38 0,52	1,38 0,36	1,42 0,42
4	Slags of Tom-Usinsk TPS	1,65 1,72	1,50 1,16	1,38 0,60	1,40 0,35	1,46 0,44

- above the line: the specimens not subjected to preliminary thermal treatment;
- below the line: the specimens subjected to preliminary thermal treatment at 350^0C.

In this interval gas evolution process ceases and depending on this expansion process comes to an end. With ongoing rise in expansion temperature to more than 1150^0C an increase in the density of the expanded granules up to 1.42…1.46g/cu.cm is observed. Microexaminations have demonstrated that pore formation occurs in the surface layer while interior layers of the specimens do not participate in pore formation. The cause of expansion discontinuance isa considerable difference in temperatures between the centre and the surface of granules. When a softened gas-impermeable shell forms on the surface of a granule the process of particle capsulation in the granule centre is not yet completed because of low temperatures and gas formation has not begun. Owing to this expansion process stops in the surface layer of granules and interior layers having no possibility of expansion remain without pores.

To provide expansion of the specimens along the whole section it was intended to study the influence of preliminary thermal treatment,i.e. preliminary heating of granules to temperatures below the beginning of gas-generating additives burn-out: 200…800^0C. The results of studying influence of preliminary thermal treatment on expansion process of a mass consisting of thermal power station slags from various plants are presented in Fig.2.

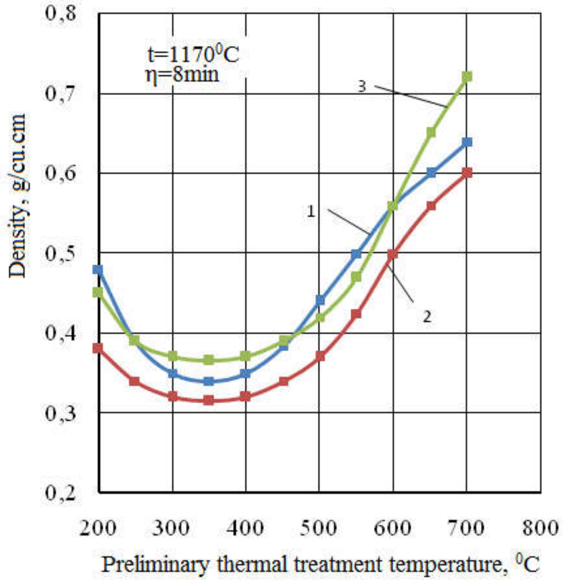

Fig 2 The influence of preliminary thermal treatment temperature on the density of the expandedspecimens of masses based on thermal power station slags from various plants

The investigation results shown in Fig.2 display that optimum pore formation of granules takes place at heating to preliminary thermal treatment temperature: 300-400^0C. The density of dried granules in this interval falls to 0.32…0.36g/cu.cm.

When a temperature is below 300^0C as well as higher than 400^0C it is impossible to achieve the coincidence of processes of material transition to pyroplastic state with gas evolution process. The preliminary thermal treatment temperature below 300^0C is not sufficient for initiation of gas evolution process but at 400^0C gas evolution begins quickly, large quantity of gases is formed, these gases easily tear the mass and release from a granule not causing full expansion process along the whole section. That is why optimum interval of preliminary thermal treatment temperature for pore formation of a mass from thermal power station slags is in the range between 300 and 400^0C.

The specimens subjected to preliminary thermal treatment expand along the whole section of a granule. The expansion beginning is observed at a temperature about 950^0C. Intense expansion proceeds to a temperature of 1150^0C (Table 2). Granule porosity of 80% is attained. Maximum pore formation develops in the expansion temperature range of 1150^0C. Pore formation process is accomplished at a temperature about 1150^0C. When expansion temperature exceeds 1200^0C fusion of granule surface and an increase in density of the expanded specimens occur. Optimum interval of expansion temperature lies near 1150^0C. At high-temperature treatment transition of material to pyroplastic state, deformation and maximum shrinkage take place during 3-4 minutes.

Gas evolution beginning and reduction in density are observed after the fourth minute. Intense expansion and porous structure formation occur for 5-9 minutes. The completion of expansion process is detected up to 10 minutes. Further increase in expansion duration brings about fusion of the surface of granules and a rise in the aggregate density.

The investigation results demonstrate that the process of granule expansion and obtaining the aggregate from thermal power station slags consists of three main stages: dispersion and formation of primary structure during granulation, sintering with the appearance of closed pores and properly expansion under pressure of gases evolving inside closed pores.

The obtained aggregate expanded at a temperature of 1150-1170^0C is characterized by dark brown color, fine porous structure. Pores are of various shapes, mostly regularly spherical, from 5-8mcm to 0.5mm in diameter. The pores are uniformly distributed throughout the granule volume starting from the granule surface to its centre. Structure elements are represented by a fine-grained vitrous substance pierced with an amorphized material of dark grey color.

Pore content reaches 68-70%. Microstructure of the aggregate manufactured on the base of TPS slags is shown in Fig.3.

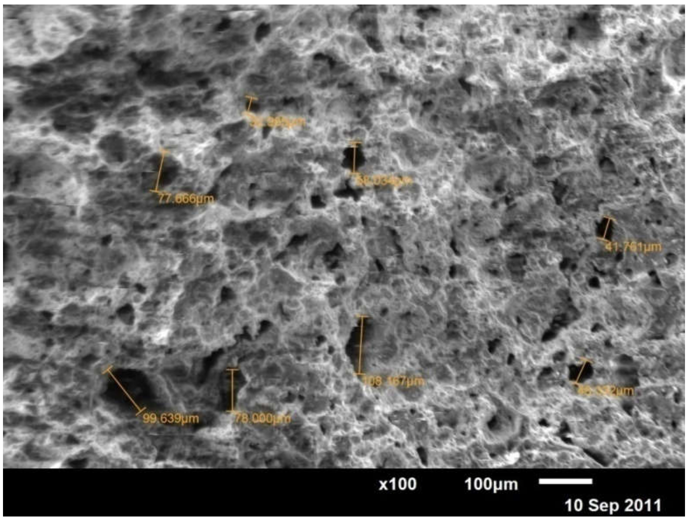

Fig 3 Microstructure of porous gravel based on TPS granulated slags (100 x magnification)

Optimum expansion temperature is in the range between 1150 and 1170^{0}C. The formation of optimum porous structure occurs at expansion duration of 6-7 minutes. Maximum pore formation of granule is observed at a temperature of 1150^{0}C. Further increase in expansion temperature leads to an insignificant rise in the density of the expanded granules. The size and quantity of pores strongly depend on an amount of a gas-generating additive introduced into raw mix composition [15]

So, theinvestigation results show that slags or ash-slag mixtures of TPS can be utilized as the basic raw stuff in the production of an artificial porous aggregate for obtaining lightweight concrete of diverse purpose.

Comparison of Predictions and Experimental Results

The investigation results have undergone semi-production tests on the operating process line of the Research and Design Institute of Building Materialsnamed after S.A.Dadashov (Baku).

Physico-mechanical characteristics of the lightweight aggregate manufactured from thermal power station slags on the process line are given in Table 3.

Analyses of the results relating to investigations of semi-production lots demonstrate that physico-mechanical characteristics of the lightweight aggregate obtained from TPS slags in all respects meet the requirements of State Standard (GOST 9757-90 "Gravel, Crushed Stone and Sand. Artificial Porous. Specifications") [16].

Table 3 Physico-mechanical characteristics of the lightweight aggregate manufacturedon the base of TPS slags

No	Properties of the aggregate of 5-20 mm fraction	Grade of the aggregate from TPS slags by bulk density			Keramzit gravel according to State Standard
		200 300	400 500	600 800	250 800
1	Density,g/cu.cm	2,45	2,43	2,48	2,52
2	Bulk density,kg/cu.m	180 270	380 480	570 760	250 800
3	Compression strength in cylinder, MPa	0,3-1,1	2,0-3,4	4,0-7,0	0,7-5,5
4	Water absorption, % by mass, per hour	22	18	16	20-26
5	Average value of gravel grain form factor	1-1,1	1	1	1,3-1,8
6	Content of split grains in gravel,% by mass	5-7	4-6	3-5	8-12
7	Frost resistance, cycles not less than	15	15	15	15

The developed technology allows to reduce bulk density of the aggregate to 30% and to increase compression strength in cylinder to 25% at the same bulk density of the aggregate. The content of split grains in gravel is minimally 3%, form factor of gravel grains equals to 1.

The obtained porous gravel is tested in concrete and optimum compositions of concrete mixes are elaborated. It has been revealed that with the use of porous gravel and sand lightweightconcrete of B2.5-B25 strength class and density of 700-1700kg/cu.m had been obtained and using natural dense sand and plasticizers lightweight concrete of B25-B40 strength class and density of 1600-1800kg/cu.m had been obtained.

CONCLUSIONS

1. The possibility of utilizing TPS slags as the basic raw material for producing an artificial porous aggregate is proved.
2. Expansion kinetics of mass based onTPS slags is studied, expansion process mechanism and regularities of porous structure formation are revealed, dependences of the principal physico-mechanical properties of the obtained aggregates on temperature-time parameters are determined.
3. Production technology of artificial porous aggregates based on TPS slags is developed, and the qualitatively new lightweight aggregate with bulk density of 180-760kg/cu.m having compression strength in cylinder of 1.1-7.0 MPa is obtained.
4. On the base of the obtained porous gravel compositions of lightweight concrete of B2.5-B40 strength class and density of 700-1800kg/cu.m for various uses are developed.

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