Application of Slags from Thermal Power Station as an Effective Initial Material in the Production of Artificial Porous Filler

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Abstract

The article is devoted to obtaining an artificial porous filler from industrial wastes, in particular from granulated slags, or ash-slag mixtures from Thermal Power Station. The developed technology provides the opportunity to expand the raw material base of artificial porous filler production for lightweight concrete, and it allows us to solve the problem of involving secondary resources in the production of construction materials and protection of the environment from pollution.

According to the results of research, the intervals of the bloating temperature have been determined, the technology of obtaining an artificial porous filler from slag and ash-slag mixtures from Thermal Power Station has been developed, and the mainphysical-mechanical properties of the filler obtained have been studied. It was established that the obtained artificial porous filler meets the requirements of the current standard in its physical-mechanical properties. It was found that on the basis of them, heat-insulating, heat-insulating-constructional and structural lightweight concrete for enclosing and bearing constructions have been obtained.

Keywords: industrial wastes, granulated slags, bloating temperature, lightweight concrete, durability/strength, density.

1. Introduction

Saving fuel and energy resources, reducing the specific consumption of materials of building constructions, improving their quality, rising thermal and protection properties, reducing the mass of buildings and structures are the most important tasks of construction.

One of the most effective ways to solve these problems is the production and application of products and constructions from lightweight concrete on artificial porous filler [1, 2, 3, 4, 5].

Currently, the most common artificial porous filler is expanded clay. At the same time, well-bloating clay rocks for the production of expanded clay gravel are not found in all regions and their reserves are decreasing with every year. Most facilities on its production are based on low-grade raw materials and correct the composition of the burden by adding various additives into it. Therefore, the use of industrial wastes, in particular slags of TPS in the production of artificial porous fillers, becomes important [6, 7, 8, 9, 10].

The use of industrial wastes in the production of artificial porous filler sprovides an opportunity to save material and natural resources, in different ways to solve the problem of involving secondary resources in the production of building materials and in protection of the environment from pollution [11, 12, 13].

2. Materials

When studying the suitability of TPS slags as the main raw material for the production of an artificial porous filler for the implementation of experimental research, slags of various facilities differing in origin and chemical composition were adopted. The chemical properties and the origin of various fuel slags are shown in Table 1. In addition to slag wastes, various binding and gas-forming additives were used in the production of raw granules.

Analysis of the results of chemical compositions of fuel slags indicates that the activity module and the slag basicity module shown in Table 1 do not differ so much between themselves. The basicity module varies within the range 0.06÷0.25, the activity module - from 0.30 to 0.57. The content of p.p.p. in chemical composition of slags is rather different, that can be the main parameter when developing the gaseous phase during bloating.

The content of p.p.p. in the chemical composition of slags of Moscow thermal power station-12 is 14.3%, and only 0.8% is in the composition of slags of St. Petersburg TPS-5. There is no p.p.p. in the composition of slags of Tom-Usinsk and Nazarov Thermal Power Stations.

The rest of constituent oxides in different slags do not differ so much from each other. There is a sufficient amount of Fe₂O₃ and FeO, as well as Na₂O + K₂O that play a big role in bloating under the influence of high temperatures and in the formation of a liquid
phase in the mass. The bulk density of fuel slags varies between 1150 ... 1300 kg/m³. The size of the main part of the fraction is less than 10.0 mm [14].

3. Experimentation

Experimental researches have been carried out with applying various fuel slags, as the main raw material, and corrective additives.

<table>
<thead>
<tr>
<th>№№</th>
<th>Name of facility</th>
<th>Chemical composition, %</th>
<th>Basicity module</th>
<th>Activity module</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Moscow/TT-12</td>
<td>SiO₂ 48,72 Al₂O₃ 28,06 Fe₂O₃ 14,42 FeO 1,16 CaO 4,19 MgO 1,11 Na₂O 0,49 K₂O 0,06</td>
<td>0,06</td>
<td>0,57</td>
</tr>
<tr>
<td>2</td>
<td>Saint Petersburg TT-5</td>
<td>SiO₂ 60,4 Al₂O₃ 22,8 Fe₂O₃ 11,5 CaO 8,96 MgO 2,08 Na₂O 3,05 K₂O 0,8</td>
<td>0,07</td>
<td>0,38</td>
</tr>
<tr>
<td>3</td>
<td>Tom-Usinsk TT</td>
<td>SiO₂ 58,09 Al₂O₃ 29,69 Fe₂O₃ 7,01 CaO 7,11 MgO 0,94 Na₂O 0,21 K₂O 2,85</td>
<td>0,04</td>
<td>0,51</td>
</tr>
<tr>
<td>4</td>
<td>Nazarov TT</td>
<td>SiO₂ 41,10 Al₂O₃ 9,47 Fe₂O₃ 2,02 CaO 11,25 MgO 3,07 Na₂O 6,5 K₂O 1,95</td>
<td>0,72</td>
<td>0,23</td>
</tr>
<tr>
<td>5</td>
<td>Voronezh TT</td>
<td>SiO₂ 51,22 Al₂O₃ 19,91 Fe₂O₃ 11,38 CaO 8,13 MgO 1,76 Na₂O 0,45 K₂O 3,36</td>
<td>0,12</td>
<td>0,38</td>
</tr>
<tr>
<td>6</td>
<td>Krasnoyarsk TT-1</td>
<td>SiO₂ 56,2 Al₂O₃ 17,2 Fe₂O₃ 9,21 CaO 1,78 MgO 12,3 Na₂O 6,5 K₂O 2,75</td>
<td>0,25</td>
<td>0,30</td>
</tr>
</tbody>
</table>

Experimental researches have been carried out in three stages: at the first stage - the preparation of burden and the production of raw granules, at the second stage - the study of kinetics of mass bloating and the structure formation of the filler, at the third stage the study of petrography and the physical-chemical properties of the obtained artificial porous filler. When conducting experimental researches, X-ray diffraction, differential-thermal and petrographic analyses have been used. Industrial tests and specification of technological parameters of production of porous gravel have been carried out on the technological line of Research and Design Institute of Building Materials named after S.A.Dadashov.

4. Samples

In research the study of kinetics of mass bloating based on granulated fuel slags, the samples were prepared from a specially prepared burden with the application of binding and gas-forming additives in the form of cylinders with a diameter and height of 16 mm, as well as granules with a diameter of 5-10 mm on a laboratory plate granulator. The X-ray diffraction, differential-thermal and petrographic analysis methods were used in order to study the processes of structure formation occurring during heating of the bloating masses and the formation of a porous structure.

5. Analytical Study

One of the main requirements for the porosity of the investigated masses is the primary crystallization of the phases in the composition of masses. From this point of view, the content of the glass is determined in all the slags investigated. The X-ray diffraction analyses show that the granulation occurs in all slags under rather normal conditions; the crystallization degree is almost absent. The glass is fixed on the roentgenogram of TPS slags as the main component (Fig. 1).

The research results on mass bloating based on TPS slags, as well as the change in density and durability of bloating samples are shown in Fig. 2. Figure 2 indicates that the process of mass porosity and the formation of the porous structure of the filler are significantly influenced by the regims of their bloating. Primary porosity occurs when the dispersed burden is granulated. The density of raw granules is 1.60 ... 1.62 g/sm³. A significant part of the pores formed during this period is fixed in the granules during their thermal treatment. The research results show that when exposure to high temperatures from 750 ... 800°C, the individual grains begin to soften, sinter and, eventually, become densified. Gas-tight closed cavities are formed, besides they are in a pyroplastic state, i.e.they have the ability to plastic deformations without breaking continuity. In this case the density reaches up to 1.8 g/sm³. With an increase of temperature above 800°C gases are evolved inside the cavity due to the formation of a gaseous phase, and they, not having an exit through the shell, create an excessive pressure in the internal cavity, under the influence of which, being softened, the granules begin to swell. A decrease in the density of the expanded granules is fixed. The bloating process continues no to a temperature of 1050 ... 1100°C. The density of the expanded granules is reduced to 1.35 ... 1.40 g/sm³ (Fig. 2, curve 1a + 5a).

When developing the burden composition, plastic clays were adopted as binding additives, and mineral, organic or organomineral additives were adopted as gasforming.

![X-ray diffraction analyses of granulated fuel slags](image)
In this interval, the process of gas evolution stops and, depending on this, the bloating process is completed. The density of the expanded granules is raised to 1.42 ... 1.50 g/sm$^3$ with a further increase in the bloating temperature above 1150°C. Microscopic research has shown that the porosity is observed in the surface layer, and the inner layers of the samples are not poroused. The reason for cessation of bloating is a large temperature difference between the center and the surface of the granules. When the softened gastight shell is formed on the surface of the granule, the process of particle encapsulation has not yet been completed and gas formation has not started in the center of the granule due to low temperatures. Therefore, the bloating process ceases on the surface layer of the granules, and the inner layers, not having the space for expansion, remain non-poroused.

Fig. 2. The influence of the bloating temperature on the density of the expanded granules from the masses on the basis of the TPS slags from various facilities

Samples that haven’t passed the preliminary thermal treatment;
Samples that have been pre-heated at a temperature of 300...500°C.

1 – slags of Moscow TPS-12;
2 – slags of Saint Petersburg TPS-5;
3 – slags of Tom-Usinsk TPS;
4 – slags of Voronezh TPS;
5 – slags of Krasnoyarsk TPS-1.

To ensure the bloating of the samples over the entire section, it was planned to study the effect of preliminary thermal treatment, i.e. preheating of the granules to temperatures below the start of burn-out of gas-forming additives 200 ... 600°C. The research results of the influence of preliminary thermal treatment on the process of mass swelling from slags of TPS from various facilities are shown in Fig. 3.

The research results shown in Fig. 3 indicate that the optimum porosity of granules occurs when the pre-heat treatment temperature is heated up to 300 ... 400°C. In this interval, the density of the dried granules is reduced to 0.32 ... 0.36 g/sm$^3$. The combination of the processes of material transition into pyroplastic state with the process of gas evolution is not ensured at temperatures below 300°C, and above 400°C. The temperature of preliminary heat treatment below 300°C is insufficient for the process of gas evolution, and the gas evolution quickly starts at 400°C, a large number of gases are formed, and they easily break out the mass and are released from the granule.
without producing a fully bloating process throughout the section. Therefore, the optimum temperature range of preliminary heat treatment for mass porosity from TPS slags is in the range of 300 ... 400°C.

Samples that have undergone preliminary heat treatment are swollen over the entire section of the granule. The start of bloating is fixed at about 850°C. The character of the curves changes abruptly. Intensive bloating continues up to the temperature 1150°C (Fig. 2 curves 1÷5). The maximum porosity is formed in the range of the swelling temperature 1100 ... 1170°C. The granule porosity is reached up to 80%. The completion of the porosity process occurs at a temperature of about 1150 ... 1160°C. The fusion of the granule surface and increase in the density of the expanded samples are observed when swelling temperature rises above 1170°C. The optimum range of bloating temperature is in the range of 1100 ... 1170°C. The research results of the bloating process and the formation of a porous structure depending on the duration of swelling are shown in Fig. 4. At a high-temperature processing of the material transition into a pyroplastic state, deformation and maximum shrinkage occur within 3 ... 4 minutes.
The start of gas evolution and the decrease of density are observed after the fourth minute. Intensive bloating and formation of a porous structure occurs within 5-9 minutes. The completion of the bloating process is fixed up to 10 minutes. A further increase in the duration of bloating leads to a fusion of the surface of the granules and increase in the density of the filler.

The research results show that the process of bloating the granule and obtaining the filler from TPS slags consists of three main stages: dispersion and formation of the primary structure during granulation, sintering with the formation of closed pores and bloating itself under pressure of the gases released inside the closed pores.

The obtained filler, swollen at a temperature of 1150-1170°C, is characterized by a dark brown color, a finely porous structure. The pores have various shapes, mostly properly spherical, with a diameter from 5-8 mc m to 0.5 mm. Pores are distributed throughout the granule volume evenly, starting from the surface of the granules to its center. The structural elements are represented by a fine-grained glassy substance, penetrated by an amorphized material of a dark gray color.

The optimal bloating temperature is in the range of 1100-1170°C. The formation of the optimum porous structure occurs with duration of bloating 6-7 minutes. Maximum porosity of the granule is fixed at a temperature 1150°C. A further increase of the bloating temperature leads to a slight increase in the density of the expanded granules. The size and quantity of pores are much dependent on the amount of gas-forming additives including into the composition of the raw mixture [15].

Thus, the research results show that slags or ash slag mixtures of TPS can be used as the main raw material in the production of an artificial porous filler for obtaining the lightweight concrete for various purposes.

6. Comparison of Forecasts and Results of Experiments

The research results passed semi-industrial tests on the experimental-technological line of Research and Design Institute of Building Materials named after S.A. Dadashov (Baku city).

The physical-mechanical properties of the lightweight filler prepared on technological line are shown in Table 2.

Analyses of the research results of semi-industrial parties show that the physical-mechanical properties of the lightweight filler obtained from TPS slags correspond to the requirements of State Standard (GOST 9757-90 “Gravel, crushed stone and sand. Artificial porous. Technical specifications”) [16].

The developed technology allows to reduce the bulk density of the filler up to 30% and to increase the compressive strength in the cylinder up to 25% at the same bulk density of the filler. The content of the chopped grains in the gravel is minimum 3-5%, and the coefficient of gravel grains form is 1.

<table>
<thead>
<tr>
<th>№№</th>
<th>Properties of filler, fractions 5-20 mm</th>
<th>Model of filler from TPS slags on bulk density</th>
<th>Expanded clay gravel by State Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density, g/cm³</td>
<td>2.46, 2.42, 2.48</td>
<td>2.52</td>
</tr>
<tr>
<td>2</td>
<td>Bulk density, kg/cm³</td>
<td>160, 370, 580</td>
<td>250, 800</td>
</tr>
<tr>
<td>3</td>
<td>Strength at cylinder pressure, MPa</td>
<td>0.3-1.2, 2.0-3.3, 4.2-7.4</td>
<td>0.7-5.5</td>
</tr>
<tr>
<td>4</td>
<td>Water absorption, % on mass, per hour</td>
<td>17, 14, 20-26</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Average coefficient value of the form</td>
<td>1-1.2, 1, 1, 1, 1.3-1.8</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>The content of chopped grains in the</td>
<td>5-5, 3-5, 2-4, 8-12</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Frost resistance, cycles of at least</td>
<td>15, 15, 15</td>
<td>15</td>
</tr>
</tbody>
</table>

The research results and semi-industrial tests show that a lightweight filler with high physical-mechanical properties can be obtained on the basis of slag wastes from TPS. They can be effectively used as the main raw material for the production of an artificial porous filler for the manufacture of lightweight heat-insulating, heat-insulating-structural and structural concrete.

The resulting porous gravel is tested in concrete and the optimum compositions of concrete mixtures are developed. It was revealed that with the use of porous gravel and sand, a lightweight concrete of the grade B2.5-B25 and density of 700-1700kg/m³ was obtained. And with the use of natural dense sand and plasticizing additives, lightweight concrete of the B25-B40 strength class and density of 1600-1800kg/m³ was obtained.

7. Conclusions

1. The possibility of using TPS slags as the main raw material for the production of an artificial porous filler has been proved.

References


[16] GOST 9757-90 "Gravel, crushed stone and sand. Artificial porous. Specifications"