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Vibration briquetting of ash of combined heat and power plant

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Abstract

Ash and slag materials of combined heat and power plant (CHPP) are a unique resource that can be successfully used in construction, road and agricultural industries. However, their industrial use is accompanied with significant organizational and technical problems. Granulation of coal ashes improves the conditions of their storage and transportation, allows mechanizing and automating the subsequent use, increases productivity, improves the working conditions and reduces the loss of raw materials and finished products. This paper proposes a method of compacting of Seversk CHPP (Russia) ash by vibration briquetting using a number of binders (polyvinyl alcohol, glyoxal, liquid sodium glass). The main characteristics of Seversk CHPP ash such as chemical composition, particle size distribution, bulk density, content of unburnt carbon and radioactivity have been determined. Investigation of the effect of binder concentration on the static strength of granules revealed that the increase of binder concentration results in the growth of static strength of the dried granules that reaches a maximum at the concentration of 10 wt %: 0.28 MPa for polyvinyl alcohol, 0.63 MPa for glyoxal and 0.40 MPa for liquid sodium glass.

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Keywords: ash and slag material, ash, fly ash component, granulation, vibration briquetting, binder, particle size distribution, bulk density

1. Introduction

Among the industry by-products the ash and slag from the combustion of coal, anthracite and slate coal of thermal power plants (combined heat and power, hydroelectric power, thermal power plants) takes one of the

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highest outputs. According to the Energy forecasting agency of the Russian Federation the annual output of ash and slag reaches approximately 30–40 million tons. Most of them are sent to the ash dumps that occupy large areas and also is one of the major sources of environment pollution. However, these materials are a unique resource that can be successfully used in construction, road and agricultural industries.[1-4] Therefore, the problem of overfilling of ash dumps and the lack of full processing of ash and slag materials is topical for today.

Currently, the problem of processing and recycling of ash and slag waste in Russia is on the focus of about 172 coal CHPP. Ash dumps accumulate a huge amount of waste (about 1.5 billion ton). The total area of these dumps is 28 thousand hectares. Its recycling in Russia is about 8%[5]. Despite all steps being taken, ash dumps generate a dust emission. In fact, at present the problem associated with the ash dumps is not solved; degree of their disposal is extremely low. Ash dumps have a negative impact on the environment and the health of surrounding settlement population and are also responsible for irreversible removal of land from beneficial use. Processing of ash not only expands a mineral resource base of the building industry, but will conserve natural resources and improve the environment in the areas where the coal energy enterprises are located. However, the use of ash and slag waste in the industry is associated with significant organizational and technical difficulties[6].

Granulation of coal ashes improves the conditions of their storage and transportation, allows mechanizing and automating the subsequent use, increases productivity, improves the working conditions and reduces the loss of raw materials and finished products. To obtain the necessary characteristics of ash granules a number of binders is used. In this study we investigated the strength characteristics of granules using polyvinyl alcohol, glyoxal and liquid sodium glass as a binder. These compounds were chosen as a binder because of their physical properties: high adhesion, binding properties and spontaneous solidification (liquid sodium glass)[7], high tensile strength and flexibility (polyvinyl alcohol)[8] and high adhesion (glyoxal).

2. Experimental

The object of the study was a mixture of ash and slag of an ash dump of Seversk combined heat and power plant (Seversk CHPP) which had been formed during the combustion of Kuzbass coal in pulverized state and fed to the ash dump by hydroremoval. The sample was taken near the hydroremoval pipe of the ash dump. The fraction with particle sizes less than 1 mm was sieved and dried. Particle size distribution, bulk density, and the content of unburnt coal particles were investigated. Ambient dose equivalent rate of photon radiation, flux density of alpha and beta-radiation were also measured.

Sieve analysis was conducted in accordance with GOST 2093-82. Size distribution of the material indicates the content of particles of different sizes. It was determined by sieving the averaged sample through a sieve set which included the sieves with hole sizes of 0.04, 0.063, 0.1, 0.125, 0.25, 0.315, and 0.5 mm. The bulk density of the material was determined according to GOST 9758-86. Determination of the content of unburnt coal particles in the material was carried out on elemental analyzer CHNS. It is used for determining the content of elements in the solid fuel (peat, coal and coke), liquid and viscous oil products (gasoline, fuel oil) and elemental analysis of biofuels.

The technology of vibration briquetting includes collecting ash, adding an aqueous solution of a binder, compacting a resulting mixture by vibration and hardening the granules in an oven. Then, the strength properties of the obtained granules are checked. The granules are cylinders with the average size of 11 mm in length and 10 mm in diameter. Polyvinyl alcohol, glyoxal and liquid sodium glass were used as binders. Using glyoxal and liquid sodium glass granules with the concentration of up to 10 wt % binder by weight were prepared (in terms of dry basis). The concentration of polyvinyl alcohol in granules (in terms of dry basis) was no more than 1.06 wt % due to the limited solubility of this compound.

The work was performed on a vibrating table. A sealing material was laid into the mould. Then, the mould was fitted and fixed on the surface of the vibrating table using clamps. Some of freshly prepared granules were placed in the oven to harden for 1.5 hours at a temperature of 110°C. Strengths of freshly prepared and dried samples were measured using the facility to determine the static strength of the granules. Granule selection to determine the static strength was performed according to the method[9].

Static strength (P) of granules in megapascal (MPa) was calculated by the formula derived in[10]:

$$P = \frac{F}{H \cdot D},$$

where F – the force required for the destruction of one granule, H;
D – granule diameter, mm;
H – granule height, mm.

3. Results and discussion

According to[11] the main components of ash and slag materials from the combustion of Kuzbass coal are silica, the content of which is approximately 62.8 wt %, and alumina containing in an amount of about 23.4 wt %. Oxides of iron, calcium, magnesium, sodium, titanium and other metals in small quantities as well as the unburnt coal particles are also included in the ash and slag materials.

Ash is a finely dispersed material which dust-forming in a dry state. Sieve analysis of the investigated material was conducted to determine the particle size distribution, the results of which are shown in Figure 1.

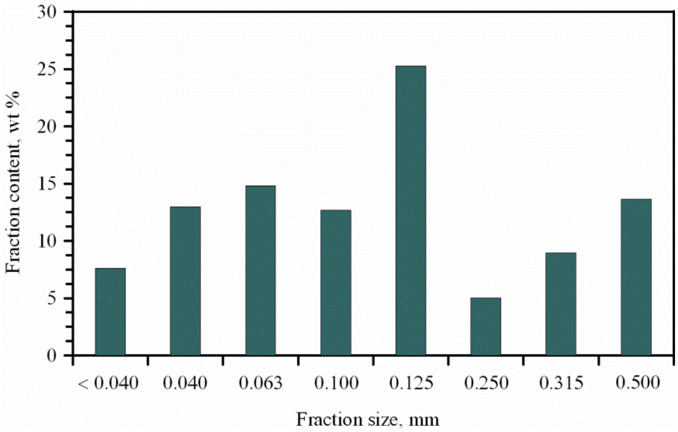

Fig. 1. Particle size distribution of ash and slag material

The object of the study does not have a strongly pronounced main fraction. Particle size distribution of the investigated material is continuous, because it contains all fractions from the smallest size of 0.04 mm to the largest size of 0.5 mm. It is known[12], that mixing of different fractions generally results in the decrease of material hollowness because the relatively small particles can be accommodated in the gaps between the larger ones, therefore, the material fills the volume more compactly.

One of the basic characteristics of free-flowing materials is density[13]. Loose bulk density is determined by the ratio of the mass of solid particles loosed freely to the volume occupied by them, taking into consideration the presence of air gaps between the particles. This index is required for the calculation of concrete or solution, the warehouse designing and selection of vehicle for the transportation of material. Bulk density is also an essential technological index that is important when dosing material at loading of processing machines. Bulk density is largely determined by the shape of the material particles. Before sieving the investigated material is characterized by the following bulk densities: loose bulk density of 0.978 g/cm^3 and packed bulk density of 1.087 g/cm^3. The dependence of the bulk density of the investigated ash and slag material of Seversk CHPP on the particle size is shown in Figure 2.

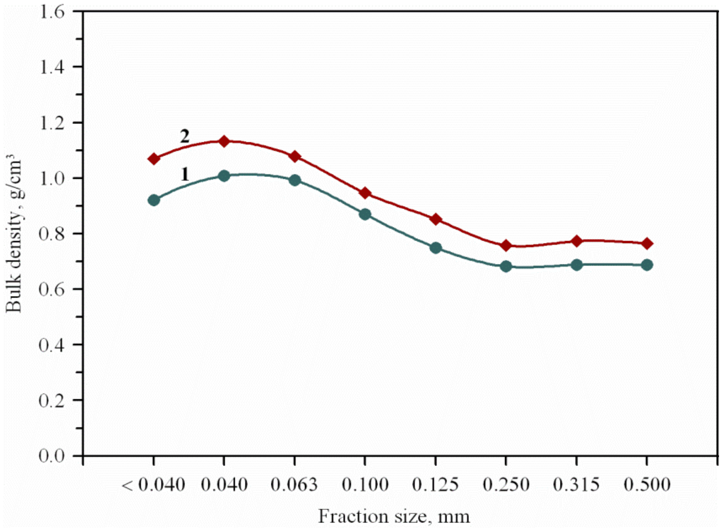

Fig. 2. Dependence of loose bulk density (1) and packed bulk density (2) of ash and slag material of Seversk CHPP on the particle size

Packed bulk density varies in the range of 1.133-0.758 g/cm^3, whereas loose bulk density is within the limits of 1.008-0.682 g/cm^3. The increase of particle size leads to the reduction of both types of bulk density.

The content of unburnt carbon particles is an important factor, because it determines the possible further material use. Often, in the ashes of combined heat and power plants a large amount of unburnt fuel (up to 40 wt %) is contained. This causes the limitation of the use of such ash as filler, especially for reinforced structures. In this case it is advisable to use ash as a raw material for the production of artificial porous fillers[12]. The results of the determination of unburnt carbon particles in the material are presented in Table 1.

Table 1. The content of unburnt carbon particles

Fraction, mm	Fraction content in sample, wt %	Carbon content in fraction, wt %
-1.0+0.5	13.657	3.2
-0.5+0.315	8.936	4.5
-0.315+0.25	5.009	12.1
-0.25+0.125	25.286	11.7
-0.125+0.1	12.664	20.9
-0.1+0.063	14.792	6.9
-0.063+0.04	12.047	4.2
-0.04+0	7.609	2.3

The content of unburnt carbon in the sample without sieving was 8.11 wt %.

One of the main reasons for restricting the use of ash and slag materials in various industries is the degree of radioactivity[14]. The use of this raw material in construction without additional checking for radiation safety is unacceptable. Results of the measurements of the ambient dose equivalent of photon radiation, flux density of alpha and beta-radiation are presented in Table 2.

Table 2. The rate of ambient dose equivalent of photon radiation, flux density of alpha and beta-radiation

Sample	ADE rate, μSv/h	Flux density, α/cm^2 min	Flux density, β/cm^2 min

Slag of Sevetsk CHPP	0.11	< 0.1	< 9.1
Ash of Sevetsk CHPP	0.15	0.2	< 9.1

The obtained results correspond to the basic sanitary rules of radiation safety[15,16]. Background ADE value of Tomsk region is from 0.11 to 0.20 μSv/h.

Ash granules with the content of the polyvinyl alcohol binder / glyoxal / liquid sodium glass with a concentration of up to 10 wt % were obtained by vibration briquetting. The strength characteristics of freshly prepared and dried granules were considered. Without a binder granules have extremely low tensile strength: 0.0115 MPa of freshly prepared granules and 0.0018 MPa of dried granules.

The results of the investigation of the three binders' (polyvinyl alcohol, glyoxal and liquid sodium glass) concentration effect on static strength of freshly prepared and dried granules are presented in Figures 3-5.

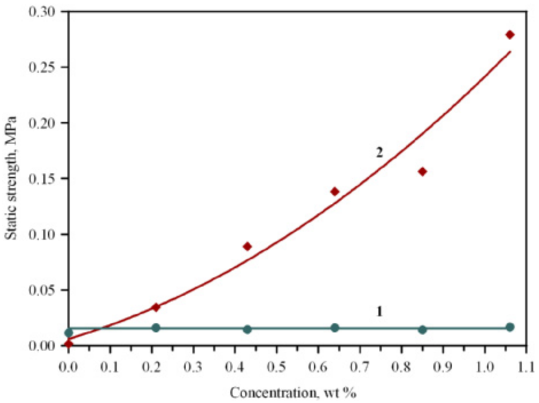

Fig. 3. Influence of polyvinyl alcohol concentration on static strength of freshly prepared (1) and dried (2) granules

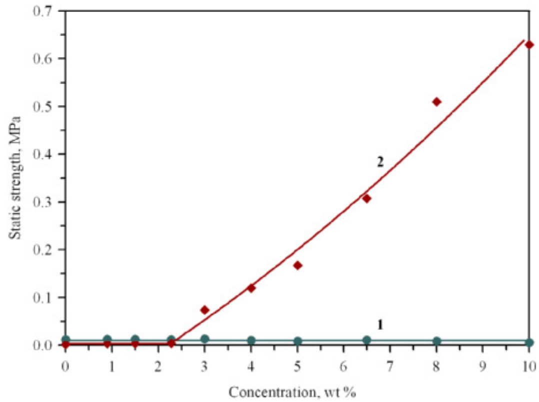

Fig. 4. Influence of glyoxal concentration on static strength of freshly prepared (1) and dried (2) granules

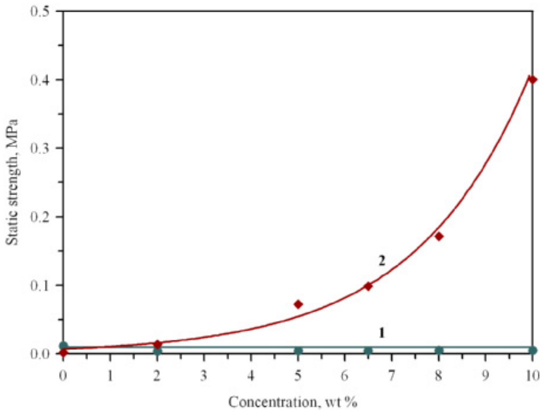

Fig. 5. Influence of liquid sodium glass concentration on static strength of freshly prepared (1) and dried (2) granules

Figures 3-5 shows that irrespective of binder nature, static strengths of freshly prepared granules do not depend on the binder concentration whereas the increase of the binder concentration leads to the growth of static strengths of dried granules.

Static strength of the granules containing polyvinyl alcohol of the concentration of 1.06 wt % was established to be 0.017 MPa of freshly prepared granules and 0.28 MPa of dried granules. Static strength of the granules prepared with glyoxal at 10 wt % is equal to 0.005 MPa of freshly prepared granules and 0.63 MPa of dried granules. The granules prepared with liquid sodium glass at the concentration of 10 wt % possess static strength of 0.005 MPa of freshly prepared granules and 0.40 MPa of dried granules.

4. Conclusion

The object of the study does not have a strongly pronounced main fraction. Particle size distribution of the investigated material is continuous, because it contains all fractions from the smallest size of 0.04 mm to the largest size of 0.5 mm. Packed bulk density varies in the range of 1.133-0.758 g/cm^3, whereas loose bulk density is within the limits of 1.008-0.682 g/cm^3. The increase of particle size leads to the reduction of both types of bulk density. The content of unburnt carbon in the sample without sieving was 8.11 wt %.

The results of measurements of ambient dose equivalent of photon radiation and flux density of alpha and beta-radiation correspond to the basic sanitary rules of radiation safety: ADE rate for Tomsk region is from 0.11 to 0.20 μSv/h.

Investigation of the binder concentration effect on static strength of the granules obtained by vibration briquetting has shown that binder concentration does not influence the strength of freshly prepared granules and is less than 0.017 MPa. Static strength of dried granules significantly depends on the binder concentration and reaches a maximum at 10 wt %: 0.28 MPa for polyvinyl alcohol, 0.63 MPa for glyoxal and 0.40 MPa for liquid sodium glass.

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