Effect of Binder on Chemically Bonded Fly Ash Aggregate Based on Kuzbass Coal Combustion Products

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***Abstract* — The possibility to test the use of alternative binders for the production of chemically bonded fly ash aggregate made of low-calcium ash of Kemerovo thermal power stations running on the coal from the Kuznetsk Coal Basin mines is described in this paper. The strength of the granules was taken as the main comparative indicator. The strength was determined by the standard cylinder compression method. The test resulted in the confirmation of the possibility to use the material such as liquid glass for production of chemically bonded fly ash aggregate. Such a change would eliminate cement from the chemically bonded fly ash aggregate production process. Moreover, replacement of the binder will reduce the density, decrease the thermal conductivity and keep the other properties of the material.**

***Keywords* — Kuznetsk Coal Basin; waste; coal combustion products; ash; liquid glass; chemically bonded fly ash aggregate.**

I. Introduction

The coal-fired power industry is widespread in Kemerovo region due to a large number of mines and open-pits. There are ten thermal power stations in Kuzbass. Their operation results in the generation of about 1.29 million tons of ash fly waste annually [1,2]. Most of the thermal power stations use coal of the Kuznetsk coal basin. Therefore, the chemical compositions of ash fly from various thermal power stations do not differ greatly. One of the methods of using this waste is to produce fly ash aggregate granules with a preferable particle size of 5-40 mm for their further use as a coarse aggregate in the production of lightweight concrete. There is a roasting technique for the industrial waste aggregate production. Such a material is called aggloporite and has the form of high strength nodules. This technique requires a lot of energy and, therefore, there are prerequisites for the production of chemically bonded fly ash aggregate [3].

When using the fly ash of the hydraulic ash removal of Kemerovo power plants, namely Novokemerovskaya combined heat and power plant and the Kemerovo State District Power Plant, for the production of chemically bonded ash fly aggregate, there is a need of an additional binder, as these ashes contain a low amount of calcium oxide CaO and cannot bind independently. Cements are known to be added as such a binder, the amount of which is 20 per cent or more of the fly ash weight [1,3].

The issue of searching for an alternative to cement as a binder in the fly ash aggregate is discussed in the article. It was decided to use a polyvinyl acetate adhesive and liquid glass as an alternative. The cement to ash ratio was taken according to the examples from the literature [3]. The amount of the input polyvinyl acetate adhesive and liquid glass was taken so as to prevent any increase in binder costs. The study will allow the cement to be excluded from the production of chemically bonded ash fly aggregate, which will reduce the production costs and increase the performance of structures built using this material.

II. Materials and Methods

The hydraulic removal ash of the Kemerovo State District Power Plant was used for the study. Table 1 shows the chemical composition of the ash [1]. As the table shows, the ash has a relatively low content of calcium oxide CaO equal to 5.7%. The main component is acid ferroaluminium silicate glass Al2O3+SiO+FeO in the amount up to 70%. The low CaO content implies a low activity not allowing the ash to harden itself.

TABLE I. THE CHEMICAL COMPOSITION OF THE ASH

Item	Content								
	SiO	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	SO_3	Al_2O_3+SiO+FeO
The ash of Kemerovo State District Power Plant	49.1	18.6	12.8	5.7	1.5	2.8	0.2	1.05	67.7

The true and the bulk density of the ash, its grain-size distribution and the fineness modulus were defined.

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TABLE II. PHYSICAL PROPERTIES OF THE ASH

	True density, кг/м^3	Bulk density, кг/м^3	Fineness modulus
The ash of Novokemerovskaya combined heat and power plant	2210	780	1,02

The true density was determined using a pycnometer. The bulk density was determined by weight quantity weighing in cylindrical vessel. To determine the grain-size distribution and the fineness modulus a portion of l2 kg was taken and screened through a standard set of test sieves. The properties of the initial components were determined in accordance with the state standard (state technical requirements GOST 25818-91. The thermal power plant fly ash for concrete). The screen analysis curve is shown in Fig. 1.

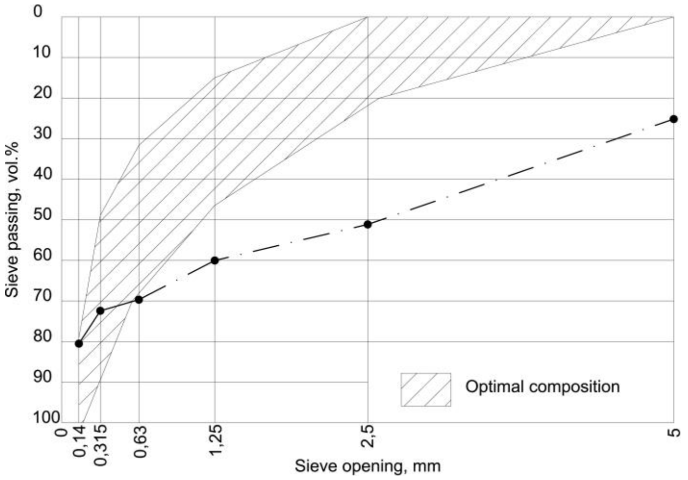

Fig. 1. Screen analysis curve of Kemerovo TPP fly ash

The ash of the Kemerovo combined heat and power plant is considered to be fine according to the State standard (State technical requirements GOST 25592-91. The fly ash mixtures of thermal power plants for concrete. Specifications). According to the requirements of this standard, the bulk density should not be greater than 1200 kg/m3, the content of calcium oxide CaO - not more than 10% by weight, magnesium oxide MgO - not more than 5% by weight, sulfur oxide SO3 - not more than 3% by weight. All these requirements The ash of the Kemerovo combined heat and power plant meets all these requirements, which allows its use as an aggregate for the lightweight concrete in the construction of residential, public and industrial buildings.

We used 400-grade Portland cement, the dispersion of D50N-grade polyvinyl acetate adhesive according to the state standard (state technical requirements GOST 18992-80. The polyvinyl acetate homopolymer coarse dispersion. Specifications), liquid glass according to the state standard (state technical requirements GOST 13078-81. Soda glass. Specifications).

The experimental part of the research included the study of the effect of the binder to aggregate ratio on the strength of the nodules. The work was conducted according to the following algorithm: batching, mixing, granulating, curing, strength test.

The binder batching was carried out in accordance with Table 3.

TABLE III. THE BINDER AMOUNT

Binder	Amount, %			
Cement	20	30	50	70
Polyvinyl acetate adhesive	1.8	2.7	4.5	6.3
Liquid glass	4.4	6.6	11	15.4

The granulation was carried out in a laboratory disc mixer. The granulation method and mode have been selected reviewing the literature [4]. The nodules hardened under normal conditions for 28 days [3,4]. For better adhesion the cement and fly ash mixture was watered not allowing any excess moisture in the mixture. The water dosing was carried out in relation to the cement weight in the ratio of 1.1 - 1.2 [4].

The tests were carried in accordance with the state standard (state technical requirements GOST 9758-86. Expanded inorganic aggregates for construction). The values of bulk density, crushability grade, the compressive strength in the cylinder were determined. The tests were conducted in the laboratory of T.F. Gorbachev Kuzbass State Technical University.

In the compression strength experiment the laboratory press P-50, the standard plunger cylinder and the laboratory electronic scales were used. The load under which the plunger submerged 2 cm into the cylinder was marked and then the compressive strength of the nodules was determined:

$$R_{сж} = \frac{P}{S_{цил}},$$

where P - load, kN; $S_{цил}$ - cylinder area, m^2.
The strength was determined for all the nodules after 28 days of normal hardening. The results of the crushing strength test in a cylinder are shown in Fig. 3.

III. RESULTS AND DISCUSSIONS

The results of the bulk density test are shown in Table 4.

TABLE IV. THE FLY ASH AGGREGATE BULK DENSITY

Binder	Bulk density on addition of binder (%) to ash weight, kg/m^3				The average density kg/m^3
	20	***30***	***50***	***70***	
Cement	664	600	602	594	612
	1,8	2,7	4,5	6,3	
Polyvinyl acetate adhesive	510	480	481	485	487
	4,4	6,6	11	15,4	
Liquid glass	512	514	503	516	512

As seen from the results, the cement nodules showed the maximum strength, liquid glass nodules showed the strength close thereto in the ratios of 11 and 15.4%.

Fig. 2. Fly ash aggregate

The polyvinyl acetate adhesive nodules showed low strength. However, the polyvinyl acetate adhesive nodules have the lowest average density, which requires increasing the amounts of the adhesive injected to obtain stronger nodules at the same density.

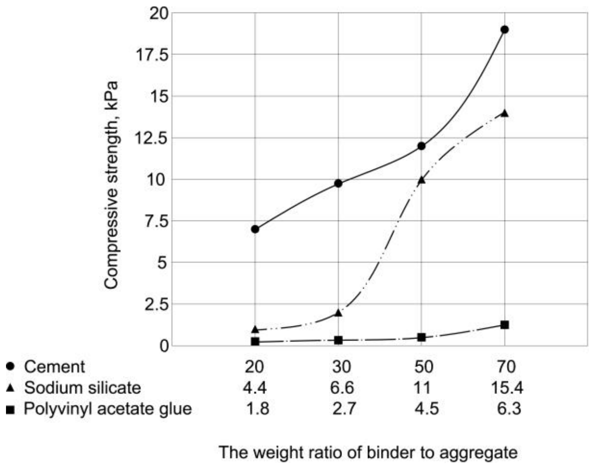

Fig. 3. The relationship of compression strength of nodules on the binder-to-aggregate ratio

IV. Conclusions

The predictably greatest strength was shown by the cement nodules, close thereto strength was shown by the liquid glass granules. The polyvinyl acetate adhesive nodules showed the lowest strength that is not sufficient for its use in building construction. The optimal binder to aggregate ratio for the liquid glass nodules is 11%.

This study shows that the use of alternative materials would eliminate the cement in the production of chemically bonded fly ash aggregates. It also reduces the density of the material, which is an important factor in the production of lightweight concrete. The results of the binder replacement will be as follows:

- the structure weight reduction;
- the reduction of the thermal conductivity of the material;
- the reduction of installation and foundation costs;
- the preservation of other properties of the material.

Upon further study, the issue of changing the properties of the material using various methods and drying modes is of interest.

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