Conference Paper

The Use of Reftinskaya State District Power Plant Fly Ash in the Production of Building Materials and Products

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Abstract

The system of dry ash–slag removal at the Reftinskaya state district power plant which provides capture, storage and shipment of fly ash to the consumers is considered in this study. The results of determination of chemical and phase composition, physical properties, melting temperature and activity of natural radionuclides of ash which is form during burning of stone coal of Ekibastuz basin are presented. Ash is acidic, superfine and refractory one with a low content of combustible substance. As to composition and properties it satisfies the requirements of Russian Standard no. 25818 and ships to consumers under Technical Conditions 5717–004–79935691–2009. The results of laboratory tests and industrial production of building materials and products on the basis of ash of Reftinskaya state district power plant are presented. It is shown that ash is used in the production of Portland cement, heavy and cellular autoclave concrete, dry mixes and can also be used as part of fly ash non-fired and agloporite gravel, ceramic bricks. The features of their production, basic physical and mechanical properties of building materials and products are described. It is shown that the introduction of a new system of dry ash removal at the state district power plant contributes to the expansion of directions and increase in the volume of ash recycling.

Keywords: Reftinskaya state district power plant, dry ash removal, fly ash, composition, properties, use, construction materials and products.

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1. Introduction

At the end of 2015 a new dry ash removal system was put into commercial operation at Reftinskaya state district power plant (a Branch of PJSC "Enel Russia") which is a member of the Enel Group and located in the Sverdlovsk region of Russia. The investments volume in the project amounted to about 12.5 billion rubles. According to the current removal system fly ash (FA) from the bunkers of the gas cleaning systems is transported by pneumatic chamber pumps to a storage facility consisting of two silos with a volume of 20,000 m^3 each which can store up to 14,000 tons of ash. Shipment of FA to consumers can be carried out simultaneously in four autotankers and six railway cars. Unclaimed volume of FA from silos is fed to the humidification and then with the pipe belt conveyor of 4.5 km length is transported to the storage dump where it is laid in layers and compacted. To prevent dusting the ash pile is covered with loamy soil on which grass is sown. Such technology of ash removal is used abroad but in Russia it is the first experience.

In 2010 an investment program “Complex processing of ash and slag wastes of thermal power plants for the period up to 2015” has developed by the Ministry of energy of the Sverdlovsk region as well as a working group to assist of the complex recycling of FA of Reftinskaya state district power plant was formed. The structure of this group included representatives of the Ministry of energy, Ministry of construction of the Sverdlovsk region, Reftinskaya state district power plant, research institute “PROECTASBEST”, Ural Federal University, environmental and other organizations. Primarily the investment program aim was the formation of the consumption market and increasing the volume of shipment of FA to consumers, reducing the area allocated for ash storage and water consumption for their disposal as well as the development of new and improvement of existing technologies of recycling and using of ash, their introduction into the economy of the region.

Reftinskaya state district power plant annually produces up to 4.5 million tons of FA and about 0.5 million tons of fuel slag during the combustion of high–ash stone coal of Ekibastuz basin located in Kazakhstan. However the volume of ash shipped to consumers does not exceed 350 thousand tons. The suitability of ashes and slags as raw material for manufacture of building materials is determined by lack or limited content of harmful components which deteriorate physical-mechanical and operational-technical properties of products or complicating technological production processes and limiting the field of its application. To assess the possibility of FA using in the production of construction products the main characteristics are environmental safety, chemical composition, the content of fuels and free calcium oxide, dispersion, melting point.

2. Results and Discussion

Ash mentioned above has the following chemical composition, mass %: 60–65 SiO_2, 23–30 $A1_2O_3$, 4–6 Fe_2O_3, 0,5–3 CaO, 0,5–1,5 MgO, 0,2–1 SO_3, 0,5–1 R_2O, 0,5–1 TiO_2, 1–4 mass losses of ignition. The phase composition of FA is represented by up to 60 % of glass as well as quartz, mullite, iron oxides and coke residues. The granulometric composition of ash varies within: less 0,01 mm – 7–20 %; 0,01–0,04 mm – 40–50 %; 0,04–0,10 mm – 20–30 %; 0,10–0,25 mm – 10–25 %; более 0,25 mm – до 25 %. Ash is characterized by the following physical properties: humidity – no more than 0.5 %, bulk density – 900–950 kg/m^3, true density – 2.1–2.2 g/cm^3, specific surface – 300–400 m^2/kg, melting temperature – above 1550 °C. In accordance with the guiding document GD 34.09.603–88 and chemical composition ash is acidic (basicity module is less than 1.0) with low content of combustibles (mass losses of ignition less than 5.0 %), fine (the specific surface area of 300 m^2/kg) and refractory (melting point above 1400 °C) [1]. A total specific effective activity of natural radionuclides is 105±28 Bq/kg which is several times lower than the standard value for construction materials and products (not more than 370 Bq/kg).

According to the main properties FA of Reftinskaya SDPP meets the requirements of Russian Standard no. 25818 and can be used as a part of building concretes and mortars [2]. From the silo warehouse the ash is shipped to the consumers according to technical conditions TC 5717-004-79935691-2009 [3]. Currently the FA used in the construction industry as the siliceous component in the production of autoclaved aerated concrete, as mineral additive in the composition of concrete and reinforced concrete structures, as filling in the dry construction mixtures. In addition there are technical proposals for the ash use as a mineral additive in grinding of Portland cement, as part of raw mixtures of cement clinker and ceramic bricks, agloporite and ash non-fired gravel (light aggregates of building concrete).

3. Fly Ash - Mineral Additive to Cement

In accordance with Russian Standard no. 31108 cement plants can produce the following types of cements with the addition of FA: Portland cement (up to 5 %), Portland cement with mineral additive (6–20 %), pozzolanic (21–35 %) and composite (11–30 %) cements [4]. Herewith acid ash should contain not less than 25 % reactive SiO_2, alkali oxides – up to 2 %, MgO – up to 5 %, free CaO is about 1 %, the mass loss on ignition – not more than 5 % and the value of t–criterion characterizing the activity of mineral additives must be over 15.

It was found that when mixing cement with fly ash of Reftinskaya SDPP the water demand of cement increases and the highest value of the t–criterion is provided in comparison with blast-furnace granular slag widely used by cement plants as a mineral additive (see Table 1). The composition and physical and mechanical properties of Portland cement with the addition of FA and blast furnace slag are presented in Table 2.

Table 1: Results of comparative tests of mineral additives in cement (authors' work).

Addition	Water-cement ratio	t-criterion	Strength [MPa]	
			flexural	compressive
Fla ash	0.48	46.74	3.7	17.9
Blast furnace slag	0.41	15.67	2.2	10.4

Table 2: Physical and mechanical properties of Portland cement with the addition of memory and blast furnace slag (authors' work).

Sample number	Type and class of cement	Amount of mineral additive in cement [%]	Normal density [%]	Initial setting time [min]	Strength [MPa]			
					flexural, after		compressive, after	
					2 days	28 days	2 days	28 days
1	CEM II/A-ASH 32.5N	10	26.4	195	2.83	7.90	13.1	42.7
2		15	27.0	200	2.79	7.20	12.4	39.5
3		20	27.8	225	2.54	7.13	12.0	35.4
4		25	28.4	220	1.99	6.52	10.5	32.3
5	CEM II/A-SLAG 32.5N	17	25.2	170	2.47	7.58	12.7	42.5
6		24	25.2	190	2.67	7.06	12.9	39.1

It was established that the increase in the FA amount increases dispersion and water demand of cement, lengthens the beginning of setting of cement paste. In comparison with the addition of slag, FA (at the same amount) slightly slows down the hardening of Portland cement both in early and late aging periods. To 28 days of hardening cements with ash in the amount of 10 and 15 % have the same bending and compressive strength compared to Portland cement containing 17 and 24 % of blast furnace granulated slag respectively but few greater strength after steaming.

4. Component of Raw Mixture of Portland Cement Clinker

Another direction but less promising may be the use of FA instead of the clay component in the raw mixture of Portland cement clinker. In comparison with natural clays the chemical composition of the ash of Ekibastuz coal is characterized by a high content of aluminum oxide and a low value of the silicate module ($Si0_2/A1_20_3+Fe_2O_3$). Therefore to obtain clinker of normal mineral composition it is necessary to introduce two corrective additives in the raw material mixture namely silica and iron-containing or use the ash from which a large part of the alumina pre-extracted [5].

JSC “Sukholozhskcement” and JSC “Starocementny zavod” cement plants is closest to the Reftinskaya SDPP. Calculation of the composition of the raw mixture on the basis of limestone, mudstone, copper slag and FA showed that ash as an aluminosilicate component can only partially replace mudstone. Ash consumption is 22–32 % by weight of mudstone or 4.5–6.5 % by weight of raw mixture, i.e. from 70 to 100 kg per 1 ton of clinker. With the complete replacement of mudstone the consumption of Ekibastuz ash in the raw clinker mixture, due to the unfavorable ratio of acid oxides, will also be insignificant and will amount to 12–14 %. Besides the ferriferous component additional high siliceous additive for example tripoli should be added in such raw mixture, i.e. instead of the traditional three–component raw material mixture of cement clinker one will obtained a four–component one the integration of which will required significant investment in the construction of the ash silo warehouse and reconstruction of the raw material shop in cement plants.

5. Ash is a Component of Heavy Concrete

Requirements for FA of thermal power plants for use in concretes are regulated by Russian Standard no. 25818 [2]. Depending on the quality indicators ashes are divided into four types:

- the first – for reinforced concrete structures and products from heavy or fine–aggregate and light concretes;

- the second – for concrete structures and products from heavy or fine–aggregate and light concretes, mortars;

- the third – for products and structures made of cellular concrete;

- the fourth – for concrete and reinforced concrete products and structures used for the construction of hydraulic structures, roads, airfields, etc.

Researches and production experience have shown that the introduction of FA in the composition of the concrete mixture has a positive effect on some operational properties of concrete, for example water resistance, corrosion resistance and strength after steaming are increased [6–8]. However the addition of coal ash in an amount of more than 15–20 % by weight of cement reduces the frost resistance of concrete. Compliance with the optimal composition and technological parameters of the production of concrete structures using FA provides concrete frost resistance up to F200–F300.

Studies by the use of Reftinskaya SDPP as a part of heavy concrete showed that the increase in its amount from 5 to 25 % by weight of cement (19–92 kg/m^3) with using a superplasticizer not only increases water demand and improves workability but also reduces the demixing of the concrete mix [9]. It was found that the addition of 5–10 % ash increases the compressive strength of concrete in the early stages and an ash increase up to 25 % reduces it by 15 % and also reduces the thermal conductivity but increases the shrinkage of concrete.

Calculation of heavy concrete compositions with partial replacement of Portland cement and quartz sand by the FA showed that its optimal content is 150 kg/m^3 for steamed concrete and 100 kg/m^3 for normal hardening concrete. In this case the savings of cement is 50–70 and 30–40 kg/m^3 of concrete respectively. It is established that the compressive strength of concrete containing FA increases with increasing ash grain size, hardening temperature and with introduction of hardening accelerators. So the addition of ash after additional grinding to a specific surface of 500 m^2/kg reduces cement consumption by 20–30 % without reducing the strength class of concrete.

6. Cellular Aerated Ash Concrete

Production of autoclaved cellular concrete is one of the most effective areas of using of FA [10]. In the Sverdlovsk region the construction of buildings and structures with the use of aerated ahs concrete is actively carried out over the past 50 years. So from the 60–ies of the last century the plant of reinforced concrete products named after the Lenin Komsomol produced sets of houses of 141 series with outer wall in the form of panels from aerated ahs concrete. As a result half of the housing stock of Yekaterinburg at that time was built using autoclaved aerated ahs concrete based on ash Reftinskaya SDPP.

Currently there are six plants in Russia for the production of autoclaved aerated ahs concrete with a total production capacity of more than 1 million m^3/year [11]. Enterprises use acidic ash replacing quartz sand in the technology in the production of cellular concrete. The use of FA as a silica component provides some technological advantages. Compared with quartz sand ash is more finely dispersed and dry which eliminates the need for grinding and simplifies storage in silos. In addition ash unlike quartz sand is mainly represented by an amorphous phase which causes its increased activity and reduces the consumption of cement and lime. Under equal conditions cellular ash concrete has a higher strength and frost resistance but greater shrinkage when drying (1.5–2 times) and water-holding capacity in comparison with a similar concrete on the sand.

Using FA of Reftinskaya SDPP the JSC “PSO Teplit” produces a small wall blocks with a density of 300–600 kg/m^3, strength class B2–B5 and thermal conductivity 0,07–0,14 W/(m·°C) from autoclaved cellular concrete. Aerated ash concrete blocks are used as a structural and thermal insulation material in the construction of houses of low and high number of storeys.

7. Dry Building Mixes

Production of dry building mixes is promising field of FA using. In 2012 at the production site of JSC “PSO Teplit” located in the village Reftinsky (Sverdlovsk region) a line for the production of dry mixes based on ash Reftinskaya SDPP with a capacity of 55 thousand tons per year was launched. The main product of the plant was the glue for cellular blocks consisting of 70 % of ash. In comparison with mixtures on quartz sand traditionally applicable for masonry blocks ash–containing glue has increased plasticity and less 1.5–2 times the consumption for laying of blocks. Also the production of plaster mixtures based on Portland cement for exterior and based on gypsum binder for interior work in which ash is used as a filler was started.

8. Non-Fired Fly Ash Gravel

Non–fired fly ash gravel is an effective aggregate for light and heavy construction concretes (as an alternative to expanded clay aggregate); it was proposed in the 50s of the last century by the Ural scientific research Institute of architecture and construction. Later at Reftinskaya SDPP its production as “consumer good” was organized. On the basis of this product precast reinforced concrete construction of garages were made. Important advantages of the artificial aggregate obtained were the absence of cement in its composition as well as relatively low investment costs for production organization and production start-up despite its low strength.

At the Department of materials science in the construction of the UFU the technology of production of non–fired fly ash gravel of increased strength from the FA of Reftinskaya SDPP which secures its application in structural concretes was developed. Properties of non-fired fly ash gravel of fraction 5–20 mm correspond to requirements of Russian Standard no. 32496 [12] and as follows: bulk density grade – M1000; the compressive strength in cylinder – 4.5–10.0 MPa; strength grade – P200–P350; water absorption – 12–15 %; frost resistance – F15–F35.

Non–fired gravel is recommended for the manufacture of concrete of strength class from B15 to B30. At Portland cement consumption of 300 kg/m^3 the compressive strength of concrete corresponded to class B22.5 and an increase in cement consumption to 500 kg/m^3 ensured an increase in strength to class B30 [13].

9. Agloporit Ash Gravel

Ashes of dry and wet catching and ash and slag mixtures from dumps with a content of the particles of unburned coal up to 15 % can be used for the production of agloporit gravel. These raw materials can have chemical composition which is regulated in enough wide limits, %: 55±10 SiO_2; 25±10 $A1_2O_3$; 10±3 Fe_2O_3; до 12 CaO+MgO. Technology of agloporit gravel includes the following basic operations: preparation of mixture components, preparation of granulated mixture, its thermal treatment on agglomeration grate and screening the product into fractions [14]. There are four grades of the bulk density: 500, 600, 700 and 800 and seven grades of strength: from P50 (compressed strength in the cylinder 1–1.3 MPa) up to P250 (3 MPa or more) for agloporit gravel. On its basis it is possible to obtain light concretes with a strength class from B3.5 to B30 and an average density of 900–1800 kg/m^3 at a cement consumption of 200–400 kg/m^3.

Agloporit gravel of 10–20 mm fractions with physical–mechanical properties that satisfy the requirements of Russian Standard no. 32496 for artificial porous aggregates for lightweight concrete (density grade – M700, strength grade – P150, water absorption – 23 %) was obtained from FA of Reftinskaya SDPP.

10. Ceramic Brick

The manufacture of ceramic bricks, stones and blocks is one of the most ash–capacious areas in the production of building materials. Ash can be used as a emaciated and burnable additive in the production of ceramic products based on clay rocks as well as the main raw material for the manufacture of ash ceramics. The optimal ash content in the charge depends on its calorific value and plasticity of the clay raw materials used. The quantity of ash entered in medium plastic clay is 30–40 vol. %, in moderately plastic – 20–30 vol. % and in low plastic – 10–20 vol. %. The ash use accelerates the drying process, reduces fuel consumption by up to 40 % and increases the strength of brick and stone. In the Sverdlovsk region the brick factories have the experience of using of ash and slag mixtures from dumps of Reftinskaya and Verkhnetagilskaya SDPPs as emaciated and burnable additives in an amount up to 20 %.

At the Department of chemical technology of ceramics and refractories UFU a technology for producing of ash ceramic bricks in which the Reftinskaya SDPP FA is the main raw material component was developed. Building bricks are obtained by semi–dry pressing and burning of a charge consisting of 80–90 % ash and 10–20 % special mineral additives. Ash ceramics has an average density of 1100-1600 kg/m^3, compressive strength – 10–60 MPa, bending strength – 2.5–10 MPa, thermal conductivity – up to 0.45 W/(m·°C), frost resistance – F25–F100 which meets the requirements of Russian Standard no. 530 for building ceramic bricks [15].

11. Conclusion

Thus industrial experience and laboratory results have shown the reasonability, perspectivity and economic efficiency of production and usage of construction products with the FA of Reftinskaya SDPP. The introduction of a new system of dry ash removal at the power plant contributes to the expansion of areas and increase the volume of ash recycling. The use of FA in the production of building materials and products is one of the effective ways to protect the environment, helps to reduce the volume of its storage on the dump and reduce the production of natural raw materials for their production.

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