

FLY ASH AS THE BASIC MATERIAL FOR INORGANIC BINDERS PRODUCTION

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Abstract

Among several other possibilities for the fly ash utilization in building materials industry and civil engineering (cement production, concrete production, blocks production etc.) another way to utilize this material is to make inorganic binder of it. This paper presents results of our investigation of lignite fly ash from thermo-power plant for the cement and the inorganic binder production. Results are satisfying regarding quality requirements for Portland and masonry cement. This kind of materials could be produced with the fly ash as main or replacing raw material.

Key words- Fly ash, deposit, building materials

1. Introduction

For several years, organizations connected with the building industry have been involved in research on energy conservation in Portland cement concretes. These organizations have been encouraging the use of less energy-intensive materials, specifically pozzolans such as fly ash as admixture or partial replacement for the relatively more expensive Portland cement. In addition to volume/mass replacement, these pozzolans can react chemically with the calcium hydroxide of the Portland cement to produce CSH gel, which is cementitious and contributes to the strength increase of the Portland cement¹⁻⁴. Today, all of the world have one problem yet. This is a problem about solid waste, great number of landfill with solid waste and problems about minimization of waste and recycling and utilization, too.

Thermo-power stations, which are using coal as the fuel, mostly have installed very efficient equipment for preventing the emission of solid particles (fly ash) to the atmosphere. Electrostatic precipitators with 3 to 5 fields collect about 99% of solid particles. For our country it is about 10,000,000 t per year of this material. Wetted material is then transferred to deposit places which presents very big ecological problem⁵⁻⁷. By definition, fly ash is a fine powder of mainly spherical, glassy particles having pozzolanic properties and consisting essentially of SiO₂ and Al₂O₃. Fly ash is obtained by electrostatic precipitation of dust-like particles from the flue gases of furnaces fired with pulverized coal. Deposit places are mostly very professionally arranged and protected, but there are still deposit places which are inconvenient for such aim. The aim of our investigations was to establish procedure for deposits of waste fly and bottom ash investigation for their safe utilization in building materials production. Reaching this aim means reducing enormous ecology problem so as the getting equal quality products (cement, mortar, concrete, bricks, etc.)^{8,9}. Our basic aim was

to establish procedure for safe utilization of deposited waste fly and bottom ash due to their chemical composition, radioactivity, unburnt carbon, demands.

If it is about the utilization in cement production e.g., it should be noted that the activity of fly ash depends not only on its own properties, but on the physical and chemical properties of the cement employed, even within the same cement type. The fly ash should therefore be tested with the cement intended to be used in practice in mortar and concrete. Unless otherwise specified, an ordinary Portland cement should be used to test basic activity.

For years the IMS Institute has been investigating possible reuse of wastes in the building materials production. Waste is unavoidable associate of power processes, chemical processes and industrial and mining operations. The biggest waste generators in our country are the thermo-power plants. Hundred of square kilometers of good soil are replaced with deposit places for fly and bottom ash.

Performed investigations were based on geological testing, chemical testing, radioactivity, heavy metals content, content of impurities, physical characteristics and pozzolanic activity of mixture of deposited fly and bottom ash. Those investigations were performed on large number of deposits.

2. Materials and methods

The following materials were used in our investigation:

1. Cement

Cement used in this research conformed with the European specification EN 197-1 for common cements.

2. Gypsum

Powdered gypsum used in this research was waste phosphogypsum conformed with the Yugoslav standard JUS B.C1.032, as the dihydrate gypsum. Gypsum was added in cement for regulation of setting time in amount of 3 % mass.

3. Mineral admixtures

The mixture of fly and bottom ash, produced as the waste material and conformed with the Yugoslav standard JUS B.C1.018. was used as mineral admixture.

The unit sample should be representative for the test purpose. The taking of each sample of at least 4 kg for complete testing is recommended. From this sample a laboratory sample of at least 1 kg is obtained by subdividing, such as quartering.

Performed investigations were based on the following methods:

- geological survey
- chemical testing
- radioactivity
- heavy metal content
- content of impurities
- physical characteristics
- pozzolanic activity

All the testing were performed according to the following testing methods:

1. Determination of strength (EN 196-1)
2. Chemical analysis (EN 196-2)
3. Determination of setting time and soundness (EN 196-3)
4. Determination of fineness (EN 196-6)

3. Results and discussion

Results of geological investigations of the deposit are presented in Table 1.

TABLE 1
Geological investigations of the deposit

Number of coreholes	Total core length, m	Average drilling length, m	Maximum drilling length, m	Minimum drilling length, m
17	149	9.22	12.0	6.5

It could be concluded that the deposit is covered with sufficient number of coreholes and enables the right evaluation of deposit in such manner to establish the opencast mining in proper way.

Our investigations were based on chemical testing, radioactivity, heavy metals content, content of impurities, physical characteristics, and pozzolanic activity of fly ash. Those investigations were performed within very long period so the variation could be estimated of some characteristics in the function of time and place of origin. We performed laboratory, semi-industrial and industrial tests with this material as the mineral admixture for cement production too.

Composition of fly ash from deposit is given in Table 2.

TABLE 2
Fly ash composition

Composition	Mass percent
Silicon dioxide (SiO ₂)	28.44-37.93
Aluminium oxide (Al ₂ O ₃)	8.25-12.37
Ferric oxide (Fe ₂ O ₃)	7.11-9.20
Calcium oxide (CaO)	20.42-24.48
Magnesium oxide (MgO)	2.01-3.40
Sulphur trioxide (SO ₃)	1.29-3.56
Sodium oxide (Na ₂ O)	0.20-0.35
Potassium oxide (K ₂ O)	0.30-0.50
Loss on ignition	13.68-24.44
Insoluble residue	26.84-52.36

The results summarized in Table 2. indicate that the fly ash constituents up to 100 % varies but the main parameters mostly satisfy the requirements of JUS B.C1.018. Loss on ignition is out of limits given in mentioned standard but it is due to hydrated water bonded to ash particles and not to unburnt carbon, and so it could be used. It is evident from the chemical analysis of the fly ash that the variations of some constituents (Al₂O₃, CaO, LOI) are large, but it could be said that besides those variations, chemical composition satisfies the requirements of JUS B.C1.018 for the most important constituents. No contamination was evident.

Radioactivity of fly ash was, also, measured because it is very important by point of view of ecology and health, and this value is 0.398-0.520 Bq/kg. It satisfies the national limits.

The study therefore suggests that partial replacement of cement by fly ash enables utilization of deposits as waste materials.

Pozzolanic activity is determined and presented in Table 3.

TABLE 3
Pozzolanic activity of fly ash

Pozzolanic activity	MPa
Flexural strength	0.4-2.4
Compressive strength	1.1-9.2

It is generally known that fly ash addition in cement results in lower initial strengths and with constant increasing in time. Activity of this kind of fly ash is rather low but it doesn't affect the basic characteristics of cement produced with the addition of 30 % fly ash. Chemical composition of cement produced with 30 % of fly ash are given in Table 4.

TABLE 4
Chemical composition of cement with 30 % of fly ash

Composition	Mass percent
SiO ₂	15.98
Al ₂ O ₃	5.15
Fe ₂ O ₃	2.05
CaO	43.11
Insoluble residue	23.69
Moisture at 105° C	1.25
Loss on ignition	3.31
CO ₂ in CaCO ₃	0.74
CaO free	0.12
CaO in CaCO ₃	0.94
CaO in CaSO ₄	1.07
SO ₃ in CaSO ₄	1.53
CaS	0.00
MgO	1.01
Alkalies as Na ₂ O	0.28
K ₂ O	0.27
MnO	0.05
FeO	0.71
P ₂ O ₅	0.06
Cl ⁻	-

The results indicated that the composition of cement satisfies the requirement of JUS EN 197-1 for common cements. The content of the minor oxides such as P₂O₅, MnO, MgO, alkalies is so small that they do not affect the cement properties.

Physical-mechanical properties of same cement are given in Table 5.

TABLE 5
Physical-mechanical properties of cement with 30 % of fly ash

Properties	Unit	Value
Sieve residue at 0.09 mm	%	4.40
Specific surface (by Blaine)	cm ² /g	3790
Density	g/cm ³	3.00
Standard consistence	%	28.70
Setting time	min	
-initial		165
-final		330
Soundness (Le Chatelier)	mm	1.0

Properties	Unit	3 days	7 days	28 days	90 days
Flexural strengths	MPa	3.5	5.1	7.1	8.1
Compressive strengths	MPa	12.5	20.9	35.0	41.1
Shrinkage	mm/m	-0.019	-0.125	-0.737	-0.812
Heat of hydration	J/g	166.0	250.0	-	-

TABLE 6
Chemical composition of masonry cement

Composition, % mass	BM	NM
SiO ₂ + Insoluble residue	19.70	21.97
Al ₂ O ₃	3.22	2.98
Fe ₂ O ₃	2.97	1.52
CaO	53.67	48.87
P ₂ O ₅	0.06	0.05
Moisture at 105° C	0.82	0.89
Loss on ignition	0.00	0.00
CO ₂	15.84	19.96
CaO free	0.53	0.86
SO ₃	1.77	2.14
MgO	1.51	1.61
K ₂ O	0.17	0.07
MnO	0.04	0.04
Na ₂ O	0.14	0.10
S	0.00	0.00
Alkalies as Na ₂ O	0.25	0.15
Water soluble sulphates		
SO ₃	1.43	1.20
SO ₄	1.72	1.44
Water soluble alkalies		
Na ₂ O	0.14	0.04
K ₂ O	0.17	0.06
Alkalies as Na ₂ O	0.25	0.08

The properties of cement, which are presented in Table 5. indicate that this cement exhibits lower density, small increase in water demands, good strengths and low heat of hydration due to fly ash addition. In other words, this cement satisfies the requirements of JUS B.C1.013 for the cement with the low heat of hydration. Flexural and compressive strengths were measured at 3 days, 7 days, 28 days and 90 days according to the procedure laid down in JUS. Three specimens were tested at the end of each curing period. The results obtained for compressive and flexural strength make it possible to formulate a hypothesis as to the role played by the different percent of fly ash.

Masonry cements (signed as BM and NM) produced with the fly ash as main constituent are presented by characteristics presented in Tables 6 and 7.

Chemical characteristics shown in Table 6. are usual for such kind of material. Soluble constituents are rather low.

TABLE 7
Physical-mechanical and mechanical properties of masonry cement

Properties	Unit	BM	NM
Sieve residue at 0.09 mm	%	0.50	1.64
Specific surface (by Blaine)	cm ² /g	5511	6060
Density	g/cm ³	2.92	2.81
Standard consistence	%	26.3	24.7
Setting time	min		
-initial		210	105
-final		315	225
Soundness (Le Chatelier)	mm	0.0	0.0
Entrained air content	%	14.0	17.5
Water retention	%	79.5	89.6

Water / binder	Flow, mm		Strength, MPa							
			7 days				28 days			
			flexural		compressive		flexural		compressive	
	BM	NM	BM	NM	BM	NM	BM	NM	BM	NM
0.50	164	158	3.9	2.0	15.7	6.6	5.5	3.2	21.4	10.9
0.533	180	-	3.9	-	14.0	-	5.1	-	19.9	-
0.54	-	182	-	1.7	-	5.9	-	3.0	-	8.6

Physico-chemical and mechanical characteristics of both masonry cements presented in Table 7. are usual for such kind of material, although fly ash is used as main constituent.

Both samples of masonry cements produced with fly ash as main constituent satisfies the requirements of Yugoslav standard JUS B.C1.010 for such kind of material.

Based on presented results, the maps of quality of some characteristics and the project for opencast mining were made.

Environment protection project for opencast mining and dispatch stations were also made, concerning measures for air and noise pollution.

The production of above mentioned cements started few years ago very successfully.

4. Conclusion

Results of large scale investigations on various deposit places of waste mixtures of fly and bottom ash led us to following conclusions and procedure:

1. Classification of wastes geared to their possible reuses as input material.
2. Basic geological examinations.
3. Detailed geological examinations.
4. Chemical, physical, mechanical testings and examination of possible harmful ingredients (radioactivity, heavy metals, etc.).
5. Monitoring of some properties in function of time or space namely origin.
6. Laboratory, semi-industrial and full scale tests in users plants.
7. Design of opencast mining.
8. Design of environment protection during opencast mining and dispatch.
9. Design of production divisions for preparing waste material to be used in some production.
10. Mining and dispatch.
11. Quality assurance and constant technical surveillance.

In this way all possible negative consequences of inadequate use of waste material are eliminated. It must be said that each deposit have to be examined by different procedure due to differences between deposit places and origin of fly and bottom ash. That was our conclusion based on very large scale of examination on deposit places.

Based on very large number of investigations from which only small part are shown in this paper, it could be concluded that the variations in quality of fly ash are large enough, so the safe utilization of this material could be done with permanent testing and separation.

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