The Application and Development of Fly Ash in China

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ABSTRACT

Coal burning electrical power is a major power supplier in China. The production of coal is 2400 million tons in 2006, and more than half was used for the fuel of power stations. The production of fly ash (including bottom ash) is 300 million tons and the accumulative amount of fly ash has exceeded 2500 million tons.

The paper presents the background of fly ash application and development in China, including the physical and chemical properties of fly ash, the pretreatment technology, the application fields of fly ash, especially in cement manufacturing and in concrete production. The paper illustrates the situation of fly ash application with several typical examples and discusses in detail its development.

1. Introduction

China is well known as having huge population, swift economic growth and high energy consumption. Statistics[1] indicated that in 2006 24 hundred million tons of standard coal was used and about 75.6% is raw coal. The structure of energy is based on raw coal, which is determined by Chinese natural conditions. In China the proven coal deposits exceed 122 thousand million tons, amounted to 10% of proven one of the world.

In except of huge reserves, China's coal resources also show the following characteristics: complete in variety but of uneven grade with small reserves of high quality coking coal and anthracite coal, widely distributed with a great disparity in the abundance for different reserve locations, with the western and northern regions rich and eastern and southern regions poor in coal reserves; a small number of surface coalmines, most of which are lignite mines; and many varieties of associated minerals

existing in the coal seam. Preliminary investigation[2] shows that the sulfur content of more than 44% coal exceeds 1% and the ash content of more than 80% coal exceeds 10%.

In China, most of the mined coal is used for electric power generation. In 2006, the national total amount of electric power generation reached up to 284 thousand million kWh, whereas coal-burning power accounts for approximately 80%[3]. Roughly calculating with that 0.38 kg of raw coal produces 1 kWh electric power and 1.34 kg of raw coal equals to 1 kg of standard coal, in 2006 1.13 thousand million tons of raw coal were used for electric power generation nationally.

Due to the lack of high quality coal and relative backward power generation technology, the burning of 1 ton of coal will produce 250 kg to 300 kg of fly ash and 20 kg to 30 kg of bottom ash. Therefore, it is deduced that in 2006 the output of fly ash was over 3 hundred million tons. In fact, the accumulative deposited amount of fly ash has exceeded 25 hundred million tons in China. The deposit of fly ash not only occupies a lot of precious land space, but also constitutes a potential threat to environment. It is obvious the comprehensive utilization of fly ash is of high significance.

2. Pretreatment of Fly Ash

Generally speaking, fly ash is one kind of pozzolana material and owns cementitious properties. In China, fly ash has been used as supplementary material in cement and concrete for long time. In order to maintain the high quality of cement and concrete, national standards have been stipulated which set up basic requirements for fly ash (Tables 1 and 2). However, the properties (Tables 3 and 4) of lager percentage of fly ash currently produced do not meet these requirements. Hence, the pretreatment of fly ash is necessary.

Table 1 the properties requirements of fly ash used as additives in cement

Index	Grade	
	I	II
Loss of ignition, %, less than	5	8
Moisture content, % , less than	1	1
SO_3, %, less than	3	3
The ratio of 28d compressive strength, %, more than	75	62

Table 2 the properties requirements of fly ash used as admixtures in concrete

Index	Grade		
	I	II	III
Fineness (residue on 0.045mm sieve), %, less than	12	20	45
The ratio of water requirement, %, less than	95	105	115
Loss of ignition, % , less than	5	8	15
Moisture content, %, less than	1	1	-
SO_3, %, less than	3	3	

Table 3 the physical properties of fly ash

Item	Range	Average	Item	Range	Average
Density, g/cm^3	1.9 ~ 2.9	2.1	Consistence, %	27.5 ~ 66.7	48.0
Bulk density, g/cm^3	531 ~ 1261	780	Water requirement, %	89 ~ 130	106
SSA, cm^2/g	998 ~ 6530	3300	The ratio of 28d compressive strength	37 ~ 85	66

Table 4 the chemical composition of fly ash

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Range, %	33.9 ~ 59.7	16.5 ~ 35.1	1.5 ~ 19.7	0.8 ~ 10.4	0.7 ~ 1.9
Average, %	50.6	27.1	7.1	2.8	1.2
Oxide	Na_2O	K_2O	SO_3	LOI	-
Range, %	0.2 ~ 1.1	0.6 ~ 2.9	0.2 ~ 1.2	1.2 ~ 23.6	
Average, %	0.5	1.3	0.3	8.2	

2.1 Carbon removing technology

As indicated in table 4, fly ash has a high value of LOI, with the average up to 8.2%. This means that the fly ash contains certain amount of unburned coal and its application in cement and concrete is also restricted.

In China research works[4,5] are conducted to develop froth flotation technology and electrostatic separation technology for carbon removing.

The froth flotation process consists of a mixer, a flotation installation and a drying separator. Fly ash is mixed with frothing agents, and the carbon particles with floats to the surface. As it is separated from the fly ash, the carbon particles will be dried and collected. With this process, the content of carbon in fly ash can be reduced to less than 1%, and the removed carbon particles can be used as fuel. The shortcoming of this technology is that the materials need to be dried before their application.

The electrostatic separation process uses a rotary tube with positive charge to absorb carbon particles with negative charges. When the rotary tube plus absorbed carbon particles rotates from the electric field, the absorbed carbon particles will be separated and collected. The process can be run continuously and the power consumption is very low, about 1 ton of material per kWh. The problem is that the removing efficiency is about 50% and the capacity of the process is only 8 ton/h. Anyway, this process has not got a real industrial application until now.

2.2 Fly ash grinding and pneumatic separation technology

When used in concrete, fly ash needs to meet the requirement for fineness. The fineness of fly ash can be controlled with pneumatic separation process or grinding plus pneumatic separation process. The application of first one can keep the separated fine particles in their original state, so that the flowability of fresh concrete can be improved. By grinding, the cementitious property of fly ash may be increased, which is beneficial to the early strength of the concrete.

In China many power plants use multistage separators for fly ash treatment. Even though the technology is a traditional one, it is very useful and the operation cost is quite low. Table 5 lists the data of fly ash properties before and after the treatment. It can be seen the properties of fly ash are improved significantly after separation.

Table 5 the contrast of fly ash properties before and after treatment

Item	Raw FA	Product 1	Product 2	Fine FA	Coarse FA
SO_3, %	0.69	0.62	0.61	0.62	0.69
SSA, cm^3/g	3600	3850	3700	8800	-
LOI, %	3.84	3.61	3.57	3.62	6.70
Fineness, 45μm residue	24.1	8.6	14.7	0	64
Ratio of water requirement	113	93	101	92	-

The grinding of fly ash is often by ball mill equipped with high efficiency separator[6]. Currently, the process with the capacity of 120 t/h is available and the fineness can be obtained with residue over 45μm sieve less than 7%.

3. The application of fly ash in cement and concrete

In China, the large-scale application of fly ash is for cement and concrete production. The use of fly ash in cement and concrete can reduce the quantity of cement clinker, save natural resource, and reduce energy consumption as well as emission.

3.1 The application of fly ash in cement production

China ranks first in cement production in the world and the output of cement reached up to 12 hundred million tons in 2006. Fly ash cement is one kind of common Portland cement. According to Chinese cement standard, fly ash cement is classified as 3 grades with 32.5 MPa, 42.5MPa and 52.5MPa at 28 days respectively and with the addition of fly ash between 20% and 40%. With the increasing addition of fly ash in cement, the early strength will decrease quickly. This is the basic reason that only 2% of common Portland cement is fly ash cement.

Some research work[7] shows that the addition of fly ash can be increased with high strength clinker. For example, in order to maintain the same strength of cement, clinker with 1 MPa higher can mix with 3% of fly ash more. Research focused on the production of cement clinker with 75 MPa is carried out, and it is expected that 35% of fly ash may be added to produce 42.5 MPa grade cement.

3.2 The application of fly ash in concrete production

Fly ash can be used directly as the admixture for concrete production. In China, the routine proportion for concrete is 50% of pure Portland cement, 25% of fly ash and 25% of slag, and the strength grade corresponds to C30 (more than 30 MPa at 28 days). With the addition of fly ash, concrete exhibits its high flowability and low heat evolution. With the addition of slag, the high early strength of concrete can be sustained and the bleeding phenomena can be avoided[8]. As shown in Table 6, with the dual additions of fly ash and slag amounted to 50%, concrete has the highest strength.

Table 6 the influence of dual additions of FA and slag (1:1)
on the strength development of concrete

FA plus slag Proportion, %	Compressive strength (MPa)			
	3d	7d	28d	60d
40	24.2	33.7	51.2	56.4
50	22.3	33.2	53.5	61.6
60	20.1	28.5	46.7	55.7
70	13.8	22.6	39.0	44.5

With the addition pf high quality fly ash, the high volume fly ash concrete can be produced. When the ratio of water to cementitious materials is limited to less than 0.3, the strength of concrete with 50% of fly ash can exceed 60 MPa at 28 days.

4. The application of fly ash produced with desulphurization process

The coal deposits in China are characterized by their high sulphur content. The burning of coal releases a lot of SO_2 into the atmosphere, which has resulted in the occurrence of sour rain frequently. It is reported[9] that the negative influence of sour rain has covered 1 million km^2 in China, and the area with pH value of annual rainfall less than 5.6 amounts to 40% of whole country's territory. The desulphurization technology has been applied in some power plants, which produces a special kind of fly ash with high calcium and high sulphur content.

Table 7 lists the chemical composition of a typical fly ash produced with desulphurization process. It indicates that except for the normal oxides, the fly ash also contains certain amount of calcium sulphate, and the calcium oxide content also increases obviously.

Table 7 the chemical composition of a typical fly ash with desulphurization process

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O
Content, %	48.52	7.61	8.00	14.07	1.12	1.88	0.32
Oxide	H_2O	f-CaO	LOI	$CaSO_4$	$CaSO_3$	$CaCO_3$	Cl^-
Content, %	1.10	9.63	4.28	3.19	0.08	2.36	0.41

Preliminary investigation[10] shows that even though the content of fly ash with desulphurization process is quite different from the ordinary one, it can be used as additive (or admixture) for cement and concrete production. Test results demonstrate that the addition of fly ash with desulphurization process has a positive effect on the strength development of concrete (Table 8), but the slump loss of fresh concrete is fluctuated sometimes. Research works are also needed to check the durability of concrete in every aspect.

Table 8 the influence of fly ash produced with desulphurization process on the strength development of concrete

Item	Compressive strength (MPa)		
	3 days	28 days	60 days
Plain	27.1	59.0	64.0
Added with 10%	28.7	55.4	60.2
Added with 20%	23.0	45.3	52.9

5. Conclusions

Coal is a major energy resource in China and is widely used for electric power generation. This also produces a huge amount of fly ash that needs to be used effectively and immediately.

Fly ash can be used as cementitious material for cement and concrete production, but pretreatment is necessary as the quality of fly ash becomes worsen mainly due to the change of power generation process.

Research work shall focus on carbon removing and multiphase separation of fly ash, as it is a starting point for large-scale application of fly ash as building materials and other application with high benefits.

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