OVERVIEW OF DIFFERENT TYPES OF FLY ASH AND THEIR USE AS A BUILDING AND CONSTRUCTION MATERIAL

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Abstract

Fly ash is produced, in massive amount, as a waste material of burning fossil fuel (coal combustion) for the thermal generation of electricity. Currently about 900 million tonnes of fly ash produced, worldwide, annually and about 30-40% of this residue is being utilized for various purposes including in cement and concrete production. Disposing the remaining percentage is costly as it should be done carefully to avoid any environmental pollution, mainly groundwater contamination.

There are different types of fly ash, including Class F and Class C, generated by burning black coal and brown coal respectively. Class F and Class C are being utilized in making building materials such as concrete, lightweight aggregate, bricks etc. Also fly ash is used as a material for road construction and earth filled dam construction.

This paper outlines an overview of using fly ash as a raw material in producing various building materials and methods of how fly ash is being incorporated with other materials. The major benefits and limitations of using fly ash as a building and construction materials are discussed.

Keywords: Fly ash, Construction material, Brown Coal, Concrete, Bricks

1. Introduction

Fly ash is generally considered as a waste material, that is produced as a by product of coal combustion process. Fly ash production has increased up to 900 million tonnes per year by 2008 and it is anticipated to increase upto about 2000 million tonnes in year 2020 (Malhotra 2008). In Australia alone, about 12 million tonnes of fly ash is produced annually by both brown coal and black coal combustion (Morrison et al. 2005). About 43 percent of this ash is re-used for various applications while the rest is being dumped as waste. Disposal of fly ash in open dumps cause massive environmental problems such as ground water contamination, spills of bulk storage and ground pollution by heavy metals. It may create various health problems. Therefore utilization of fly ash as a useful product is essential in today's world for a sustainable coal industry.

Since fly ash shows a wide range of physical and chemical properties, similar to cement, American Society for Testing and Materials (ASTM), as cited in French & Smitham (2007), classifies main types of fly ash for various applications. They are Class F and Class C which are categorized depending upon chemical properties of fly ash. Class F fly ash, is available in larger quantities, which is generally low in lime, less than 15%, and contains greater combination of silica, alumina and iron (more than 70%) compared to Class C fly ash. Class F is a solution to a wide range of summer concreting problems and it is often recommended for using where concrete may be exposed to sulphate ions in soil and ground water. Class C fly ash normally comes from coal which produces an ash with higher lime content, generally more than 15%, often as high as 30%. Also, high Calcium Oxide (CaO) gives Class C unique self hardening characteristics. Class C is mostly used in situations where higher early strengths are important.

2. Physical and chemical properties of fly ash

Classification and selection of fly ash depend on the properties of it in order to utilize in an efficient way. Selection involves mainly monitoring the fineness and loss on ignition (LOI) of the fly ash (Sear 2001). In addition there are other physical and chemical properties involve in identifying different categories of fly ash.

The physical properties of fly ash depend on the nature of coal; mineral matter chemistry and mineralogy, furnace design, furnace operation and method of particulate control; such as Sulphur Oxide (SOx) and Nitrogen Oxide (NOx) control technologies (French et al. 2007). Fly ash particles are generally spherical in shape and ranging from 0.5 µm to 100 µm. A number of studies have been done by various researchers to study on physical properties of fly ash (table 1). These properties influence the properties of the final product such as workability, pumpability, water requirement as well as permeability.

Table 1: Physical properties of fly ash

Property	*Maher & Balaguru (1993)*	*Mitash N (2007)*	*Huang et a (1995)*	*Muhardi et al (2010)*
Specific gravity	*2.54*	*1.9-2.55*	*2.06*	*2.3*
Moisture content	*13.60%*		*0.53%*	*19.75%*
Fineness			*13.80% in No. 325*	*0.6 - 0.001 mm*
LOI			*7.5*	
Maximum dry density	*1.65* g/cm^3	*0.9-1.6* g/cm^3		*1.53* g/cm^3*cc*
uniformity coefficient	*2.5*	*3.1-10.7*		
liquid limit	*16.8*			
permeability	0.9×10^{-5} *cm/s*	$10^{-5} - 10^{-3}$ *cm/s*		4.87×10^{-7} *cm/s*
angle of internal friction		*30°- 40°*		*23°-41°*
cohesion		*Negligible*		*3-34 kPa*
compression index		*0.05-0.4*		*0.15*
coefficient of consolidation				*0.1 - 0.5* m^2*/year*

It can be seen that chemical compounds of fly ash is almost the same as in Portland cement (Table 2). Major proportion of fly ash; Silica Oxide (SiO), Aluminium Oxide (Al_2O_3), Iron Oxide (Fe_2O_3) and CaO, is the same as major compounds found in cement. However the proportion of each compound differs significantly comparing fly ash (class F & class C) and Portland cement and natural pozzolan (class N)

Table 2: Chemical properties of fly ash and Portland cement (Headwaters, 2005)

Chemical compound	*Pozzolan type*			*Cement*
	Class F	*Class C*	*Class N*	
SiO	*54.90*	*39.90*	*58.20*	*22.60*
Al_2O_3	*25.80*	*16.70*	*18.40*	*4.30*
Fe_2O_3	*6.90*	*5.80*	*9.30*	*2.40*
CaO	*8.70*	*24.30*	*3.30*	*64.40*
MgO	*1.80*	*4.60*	*3.90*	*2.10*
SO_3	*0.60*	*3.30*	*1.10*	*2.30*
Na_2O *&* K_2O	*0.60*	*1.30*	*1.10*	*0.60*

It can be seen that Portland cement is rich in lime (CaO) while fly ash is low. Fly ash is high in reactive silicates while Portland cement has smaller amounts. With these chemical properties it is recommended to use fly ash with Portland cement since the pozzolanic activity of fly ash causes the fly ash to combine with free lime to produce the same cementations compounds formed by the hydration of Portland cement as shown in Figure 1 (Headwaters 2005).

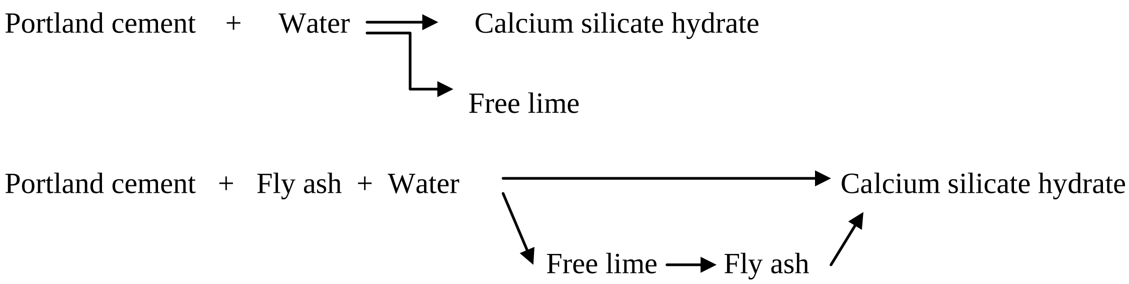

Figure 1: Reaction of fly ash in cement

It can be seen that pozzolanic reaction not only provides strength but also prevents efflorescence, which occurs due to free lime leaching out from hardened concrete.

3. Utilization of fly ash

A considerable amount of research works have been done to find useful applications of fly ash. Henry Liu et al (2005) introduced a brick using Class C fly ash, water and air entraining agent. When casting the brick, it was compressed at 27MPa and used steam bath for curing for 24 hours at 150 °F (66 °C). These bricks have improved freezing and thawing properties, as well as achieved greater durability. However, the cost was 20% less than the traditional clay bricks. Bijen (2005) recommended 40% of fly ash use with 8-10% of lime and definite proportion of water. He recommended the following properties of fly ash, as shown in table 3, may be most suitable compound composition for this type of application.

Table 3: Recommended properties of fly ash in brick manufacturing (Bijen 2005)

Chemical composition	*Mass percentage*
LOI	*6*
SO3	*2.5*
MgO	*2*
SiO2	*40*
Fineness	
Residue on sieve: 200µm	*<10*
90µm	*<20*
60µm	*<30*

An advantage in using fly ash is that heat flow resistance may be 15-40% higher than in quartz sand. Therefore fly ash increases thermal insulation of the final product as well as reduces the heat of hydration in concrete.

Kayali (2005) produced high performance fly ash bricks, using fly ash, water & chemical additives such as plasticiser, Carboxymethyl Cellulose (CMC) and $CaCl_2$ in small quantities. Addition of $CaCl_2$ as an admixture would help to accelerate the curing process significantly however it would increase corrosion of any metallic object which may be in contact with these bricks. Raw bricks were cured for three days before firing. These fly ash bricks were about 28% lighter than clay bricks and possessed compressive strength higher than 40MPa.

Various methods have been used by past researchers in making fly ash cement composites. Ashby (1990) explains three ways of incorporating fly ash in cement: as a part of cementitious material, or as a fine aggregate or a combination of cementitious material and fine aggregate. The percentage of fly ash in concrete can be as high as 40% of concrete mix and using chemical admixture can improve curing time of fly ash concrete. Concrete containing fly ash and chemical admixture absorb less water than plain concrete.

Maher & Balaguru (1993) investigated the usability of flowable high volume fly ash cement composite. Cylindrical specimens were casted using plastic moulds and compaction was achieved using a table vibrator. Although the mixing and casting method was bit similar to that of clay bricks, they adopted a different curing procedure. They have used humid rooms maintained at 100% relative humidity and 22^{o}C for three days before demoulding as well as until testing. The specimens were tested for 3, 7, 28, 56, 90 and 180 day compressive strength. They reported that a sand-cement ratio of 15:1 and w/c ratio of 0.3 seem to provide the best result for compressive strength of 21MPa at 180 days.

Huang et al (1995) have recommended Class F Fly ash, with super plasticizers, lime, silica fume, sludge treatment agent & Portland cement to be used with a water/cement ratio of 0.58 and fine aggregate/cement ratio of 2.75 in making cement based fly ash blocks. Silica fume and sludge treatment agent were used to improve the strength. Based on 90 day strength, they recommended that fly ash blocks can be used as secondary structural members for marine engineering since the leaching of the block’s soluble components was very low, and therefore the solid blocks were considered as environmentally acceptable in the seawater. Naik, et al., 2006 researched Controlled Low Strength Material (CLSM) using fly ash. They used moist curing after typical curing. The specimens (150 x 300 mm cylinders) were typically cured for one day in their moulds at about 23^{o}C. They found that the rate of strength gain was higher for the fly ash mixtures containing aggregates than for fly ash mixture containing no aggregate.

Chester et al (2001) have investigated lightweight fired bricks from Class F fly ash. The compressive strength of the brick was similar to that of common clay bricks. They have concluded the optimum composition as a combination of 70/30 for fly ash/common sand with 15% sodium silicate and 5% lime to produce best performing brick in terms of strength, mouldability and water absorption.

4. Benefits of using fly ash in manufacturing building materials

Fly ash can greatly improve the workability of concrete as it contains more fine particles than cement, reduced water of convenience by 5%to 10% and greater consolidation. Also, the segregation and bleeding are reduced due to increased cohesiveness of fly ash concrete. Fly ash increases the cementitious compounds, minimizes water demand, and reduces bleed channels, which increase concrete density. These factors yield concrete of low permeability with low internal voids. Durability is increased with regards to freeze-thaw damage and disintegration from attack by acids, salts or sulphates. Usually Class F fly ash has better capability to increase the resistance to sulphate attack and reduce the heat of hydration & the rate of heat generation of concrete. However, class C fly ash has a potential in developing higher early strengths since it can generate the pozzolanic reaction by its own lime content (Malhotra 2008). Further, fly ash causes increased later age strength, marginally reduced drying strength and reduced creep. Placement of concrete at lower slumps can be achieved by using fly ash in the mix of about 25% substitution for cement. This maintains an excellent workability, better finishing textures while keeping equal strength, durability and better pumpability of fly ash concrete.

As reviewed in the past literature, black coal fly ash was mainly used by many researches since it contains fewer impurities compared to brown coal fly ash. Brown coal fly ash has the same potential as in black coal, if it is used in a proper manner. Also the disposal percentage of brown coal fly ash can be reduced, if it is utilized in a better purpose such as manufacturing building materials. Therefore it is necessary to focus on new researches to develop methods of incorporating brown coal fly ash in building material products. This will eventually minimise the environmental pollution caused by disposal of brown coal fly ash.

5. Conclusion

Utilization of fly ash in manufacturing building materials has increased significantly due to its increasing availability and massive environmental problems caused by disposal of fly ash. Two types of fly ash have been defined as class F and class C in which high lime content is identified. Physical properties of fly ash may vary depending on the nature of coal; rank, mineral matter chemistry and mineralogy, furnace design, furnace operation and method of particulate control, while chemical properties are less dependent on those factors. Fly ash has been incorporated in many different ways in manufacturing bricks, concrete and cement-composites such as slabs, beams, columns, wall panels, sheets, pipes etc. Generally it is recommended to use around 25% of fly ash as replacement of cement in order to obtain effective resultant end products. Fly ash improves workability, freeze/thaw durability, density and pumpability while it reduces unwanted effects such as water demand, permeability and alkali/silica reaction in concrete.

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