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Bottom Ash in Concrete

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ABSTRACT

From the coal generating system, the waste materials that produced are the bottom ash and fly ash. Bottom ash is collected at the bottom of boiler or furnace and sometimes it is placed on the surface of the chamber in a water-filled hopper. High-pressure water is used to remove the bottom ash from the chamber. Fly ash is disposed to atmosphere by tall chimney. 80% of the product of electric coal power plant will become fly ash and the remaining 20% is bottom ash. The bottom ash is physically coarse, porous, light, glassy, granular, greyish and incombustible materials which are suitable to be used in concrete for civil engineering application. The type and properties of bottom ash produced depend on the type of boiler or furnace and also the sources of raw coal. With the chemical analysis and physical testing, the bottom ash shows unique properties that can be applied in concrete. Many researchers discovered that the bottom ash can be functioning as a material in producing various types of concrete material, new concrete technology, masonry engineering and also highway engineering application .

Introduction

Bottom ash from electric coal power plant is estimated to increase in the developing country such as South-East Asia, China, India and other countries where waste material landfill for dump area is limited. In peninsular of Malaysia, there are 4 electric power plants that use coal as a power sources to generate electricity. They are located in Perak, Johor, Selangor and Negeri Sembilan. The private sector is building a 2100 MW capacity coal power plant in Johor and another private company group is building another 1700 MW capacity plant in Negeri Sembilan. TNB's electric power plant in Perak which uses coal as raw material began its operations in September 2002 with a capacity of 2100 MW.

This raw coal was taken directly from Sarawak. TNB also imports high quality coal from Indonesia, Australia, the United States, Canada and

China. compared to other fossil fuels. The use of coal for electric power generation has increased due to the increase of petroleum price and the decrease of its reserves.

From the process of electric coal power plant, two major waste products can be produced and they are fly ash and bottom ash. Fly ash is a waste product from precipitator zone and bottom ash is generated from boiler or furnace zone. Therefore, to control fly ash and dust hovering in the atmosphere, recipients electrostatics was built in order to trap 99% of ash and dust. While another waste materials which are collected after the treatment process of electricity is bottom ash. Bottom ash that is collected at the bottom of the combustion chamber in a water-filled hopper is removed by means of high-pressure water jets and conveyed by sluiceways to a decanting basin for dewatering followed by stockpiling and possibly crushing (Steam, 1978). Figure 1 shows the typical steam generating system that illustrated the bottom ash and fly ash. Table 1 presents the physical properties of bottom ash. The specific gravity (SG) of bottom ash is around 2 – 3 and shows the higher carbon content that ensuing in lower specific gravity. Besides that, the bottom ash is not classified as plasticity and low density material.

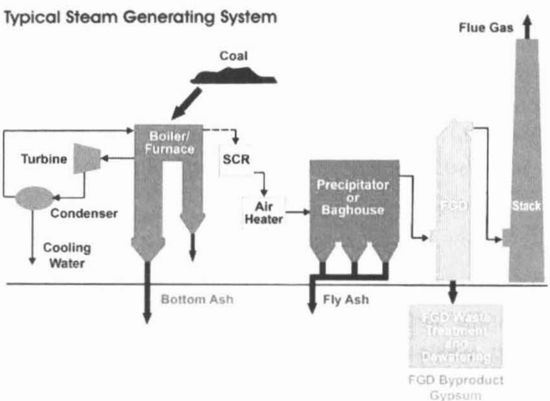

Figure 1: The production of coal combustion by-products in steam generating system (NETL, 2006).

Table 1: The typical physical properties of bottom ash (Majizadeh *et al.*, 1979)

Physical Property	Bottom Ash
Specific Gravity (SG)	2.1 – 2.7
Dry Density	7.07 - 15.72 kN/m^3(45 – 100 Ib/ft^3)
Plasticity	None
Water Absorption	0.8 – 2.0 %

For coal type comparison of bottom ash, the differences in the percentage of various elements are shown in the Table 2. The typical chemical composition of bottom ash is referred to burning lignite, bituminous coal and sub-bituminous coal.

Table 2: Chemical Composition of Bottom Ash (Sources: WE Energy Utilization Handbook, 2000)

Compound	Symbol	Bituminous Coal % (Mass)	Sub Bituminous Coal % (Mass)	Lignite % (Mass)
Silica Dioxide	SiO_2	61.0	46.75	70.0
Aluminum Oxide	Al_2O_3	25.4	18.76	15.9
Iron Oxide	Fe_2O_3	6.6	5.91	2.0
Calcium Oxide	CaO	1.5	17.80	6.0
Magnesium Oxide	MgO	1.0	3.96	1.9
Sodium Oxide	Na_2O	0.9	1.28	0.6
Potassium Oxide	K_2O	0.2	0.31	0.1

Chemical analysis of bottom ash is reported as the mass percent of each equivalent oxide. Based on the chemical analysis, it is normally measured that about 80-90% of weight of the bottom ash contains O, Si, Fe, Ca, Al, Na, K, and C with minor elements such Mg, Ti, Cl, Mn, Ba, Zn, Cu, Pb and Cr. Some of the minor elements and many of the trace elements are enriched in the bottom ash. The chemical oxides in cement consist mainly of lime, silica, alumina and iron oxide and these oxides have their function in concrete. When compared with bottom ash, the chemical oxides are similar to cement chemical oxides.

Figure 2 illustrates the common applications of coal bottom ash. The major application of bottom ash is referred to structural fills embankments part, cement clinker, road pavement, aggregate and concrete application. According to 2006 statistics, 45% bottom ash is used in transportation applications such as asphalt concrete aggregate, road base material, embankment or backfill material and structural fill (American Coal Ash Association - ACAA, 2006). In Malaysia, the use of bottom ash is very minimal due to lack of knowledge and research. Hence, this paper reviews the application of bottom ash in concrete according to researchers' study.

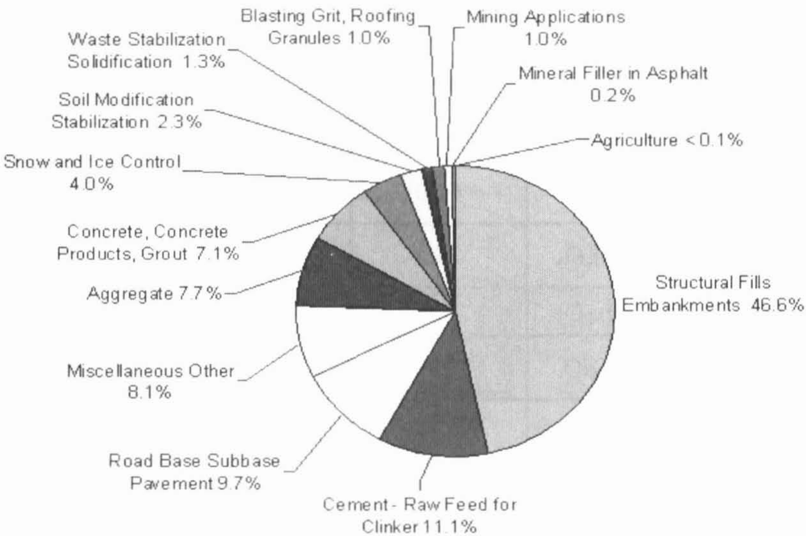

Figure 2: Bottom ash applications as a percentage of totals reused (ACAA, 2006)

Material

Bottom ash was collected from the ash pond of TNB electric coal power plant, TNB Janamanjung Sdn. Bhd, Manjung, Perak.

This bottom ash is Q – DEJ + 10% Lati Coal type. Q – DEJ and Lati Coal type are noted as the origin of the coal located in Indonesia. Ash content in Q – DEJ and Lati was 10 – 13 % and 4% respectively. The Q – DEJ contains high fly ash and bottom ash while Lati contains low fly ash and high bottom ash. This bottom ash has 9.76 pH concentrations. The discharging method of bottom ash was using circulating water and free from salt and chloride. The bottom ash used is directly applied into concrete without pre-treatment. In Figure 3, the difference between original bottom ash (dark grey) and natural sand (brown) has been clearly shown according to their colour.

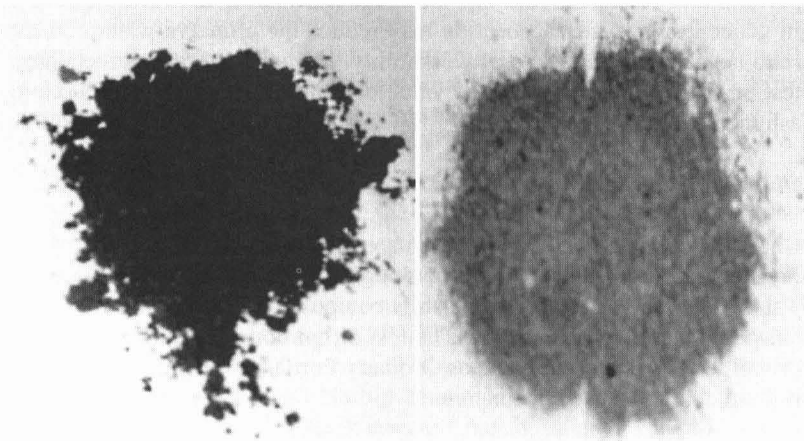

Figure 3: Original bottom ash samples and sand

Experimental Work

Physical Properties

Table 3 show the comparison physical properties data of bottom ash with natural sand.

Table 3: The physical properties of bottom ash and natural sand

Properties	Bottom Ash	Natural Sand
Specific Gravity (SG)	1.84	2.66
Water Absorption	26.6%	1.3%

Specific gravity of bottom ash was determined by in-house method and results an average specific gravity which is 1.84 while natural sand has higher specific gravity of 2.66. The experimental specific gravity is lower than result in Table 1. It was shows that the bottom ash is 30% lighter than natural sand and may producing lighter concrete. However the bottom ash has higher water absorption of 26.6% while natural sand is only 1.3%. Higher water absorption indicates that the bottom ash has high porosity. The pores at the surface particle of bottom ash affect the bond between the aggregate and cement paste and may reducing the strength of concrete. Besides that, bottom ash has water absorption higher than 2-3%, therefore it may need to be treated as suspect and may lead to concrete performance such as higher dry shrinkage (Alexander & Mindess, 2005). In general, high water absorption may reduce the effective water cement ratio hence results in a loss of workability. It was found during the slump test on fresh concrete where the value of slump decreased as the bottom ash increased.

Chemical Properties

Chemical composition of the bottom ash was determined by using by X-ray fluorescence (XRF) method on 500g coal. Its results are tabulated in Table 4. In general, the bottom ash is composed of 39.4% and 34.3% of silica and alumina respectively. The lost of ignition is 0.63. The chemical properties are almost the same as Ordinary Portland Cement (OPC) hence it is suitable to be used in concrete.

Table 4: Chemical properties of bottom ash and cement (OPC)

Chemical Composition	Bottom Ash Weight (%)	Cement (OPC) (%)
Silica, SiO_2	39.4	20.6
Alumina, Al_2O_3	34.3	6.3
Iron Oxide, Fe_2O_3	15	3.6
Titania, TiO_2	3.08	-
Magnesia, MgO	1.57	-
Calcium Oxide, CaO	6.13	63
LOI at 1000°C	0.63	-

Application in concrete

Aggregate

There are two types of aggregate in producing concrete while one type of concrete in producing mortar. In concrete, the fine aggregate and coarse aggregate are used in mixing process. Only fine aggregate is used in mortar. The size of fine aggregate is 5 mm and passing 5 mm and the size of coarse aggregate normally is 10mm, 20mm and 40mm. Every size of coarse aggregate depends on the application. Besides that, the physical properties of the aggregate or aggregate replacement must follow the main criteria such as surface texture, moisture content and shape. With similar physical properties of natural aggregate, bottom ash are being investigated as aggregate replacement. This aggregate is used in concrete, mortar and masonry application. Bottom ash has also been extensively used as filler material for aggregate in structural application, road based aggregate, and also aggregate in lightweight concrete in other country.

Many investigation found that the bottom ash has some cementaneous properties in which may increase the strength and long-term than concrete with natural sand. The strength and drying shrinkage of concretes with furnace bottom ash (FBA) as sand replacement at 0%, 30%, 50%, 70% and 100% by mass, were studied at fixed water–cement ratios (W/C) and fixed slump ranges (Bai *et al*, 2005). Besides that, the bottom ash is used as artificial aggregate in concrete. Zhang and Zhang (2011) reported the bottom ash collected from Harbin Municipal Solid Incinerator Plant as coarse aggregate replacement in concrete has the same development trend with ordinary concrete. Kim and Lee (2011) conducted fine and coarse aggregate replacement with percentages of 25%, 50%, 75% and 100% to normal sand and gravel. Experimental result demonstrated shows that it is possible to partially replace fine aggregate with bottom ash in concrete and it is to be subjected to high temperature response (Yuksel *et.al*, 2011). Topcu and Bilir (2010) studied the effect of the bottom ash as fine aggregate replacement (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%) in mortar or concrete on shrinkage cracking. Kou and Poon (2009) comparison studied of properties concrete with the use river sand, crushed fine stone (CFS), bottom ash and fine recycled aggregate as fine aggregate. Bottom ash as coarse aggregate replacement proportion rate has different effects on compressive strength in different water cement ratio (Zhang & Zhang, 2011).

Cement

When referred to chemical composition, the bottom ash is suitable after ground until same size of Portland cement.

Many researchers also study the percentage proportion of bottom ash to replace with partially or fully. For example, Hsu *et. al, (*2011) studied and indicated with ingredients of bottom ash as principal compositions used in production of cement. Evaluation of ground bottom ash compressive strength were carried out by mixing in varying amounts of Portland cement for curing purpose of 2, 7, 28 and 90 days (Kizgut *et. al*, 2010). The investigation of the pozzolonic reactions and engineering properties of municipal solid waste incinerator (MSWI) bottom ash in slag blended cements (SBC) with various replacement ratios (Lin and Lin, 2006). Besides that, bottom ash has also been studied as the potential pozzolanic material and the results indicate that ground bottom ash could be used as a good pozzolanic material in concrete (Jaturapitakkul & Cheerarot, 2003). Hsu *et. al* (2011) studied and analysed the mechanical properties of bottom ash as substituting material in portland cement. Since many researchers studied about potential ground bottom ash as partial cement replacement, the emission of carbon dioxide from high comsumption of portland cement can be reduced. Thus, the bottom ash can be supported to green technology in construction activity and can also deduct the environmental impact factor.

Special concrete

Special concrete is the new technology of concrete to enhance the properties of concrete such as increasing workability and strength. Special concrete is used according to their application, to reduce manpower in construction and time schedule. So the bottom ash has a good potential as raw material replacement, additional material and alternative material that showed improvement to construction technology and activity. Besides that, many researchers have explored utilized bottom ash in special concrete application such as roller compacted concrete and self-compacting concrete. Ghafoori *et. al* (1997) carried out investigations on a series of laboratory-made roller compacted concretes (RCC) containing high-calcium dry bottom ash as a fine aggregate. Kasemchaisiri *et. al*,(2008) presented the test results of mechanical properties of self-compacting concrete (SCC) incorporating bottom ash as partial sand replacement of 10%, 20% and 30% by weight. 10% replacement by weight of total fine aggregate showed a better durability, chloride penetration, carbonation depth and drying shrinkage compare to control SCC mix. Lee *et. al* (2010) reported that the bottom ash can be applied as aggregate in fiber-reinforced cellular concrete which improved the compressive strength and also reduced problem related to waste. The polymeric resin content of bottom ash concrete increased and drastically strength would also be increased (Zhao *et. al*, 2011).

Highway application

Hjelmar *et al* (2006) reported that bottom ash or municipal solid waste incinerator (MSWI) bottom ash in Denmark as the utilisation for back-filling (landfill) and as sub-based in road construction purposes. Vorobieff (2010) investigated the challenges confronting sustainable practices for concrete pavement design and construction in Australia by using bottom ash. The comparison study of construction material in road construction by using coal fly ash, bottom ash and recycled concrete pavement are carried out because of cost, environmental pollutants and energy consumption (Chowdhury *et. al*, 2010). Hassan and Khalid (2010) experimental investigated the mechanical and environmental characteristics of bituminous mixtures containing high bottom ash contents. Yoon *et. al,* (2009) described the construction and the instrumentation of a demonstration embankment built with an ash mixture (60: 40 by weight of fly ash: bottom ash). The bottom ash is also useful in highway construction activity such as pavement material and back-filling for protecting landslide. In Malaysia, there is lack of study in highway application that fully or partially used bottom ash.

Conclusion and Recommendation

The following conclusions may be drawn from this study:

1. Physical properties which are conducted to the bottom ash from electric coal power plant, TNB found that this material is suitable to be used for mortar rather than concreting sand.
2. Chemical composition that consist silica and alumina in bottom ash is showed high potential as cement and aggregate substitution in concrete and mortar.
3. From the application of bottom ash, a lot of study has been done from the usage in aggregate especially fine aggregate. This is because the shape, size and other physical properties are similar to natural sand.

The following recommendations can be made from the study:

1. The bottom ash should be washed with water or any chemical to reduce amount of carbon that will damage the bonding in concrete.
2. Due to high water absorption, bottom ash should be included in designing the concrete mix, in which modifying the effective water-cement ratio.
3. Expand the study to evaluate the percentage of usage bottom ash in concrete, concrete application and highway engineering application.

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