EFFECT OF COAL BOTTOM ASH AS A PARTIAL REPLACEMENT OF SAND ON PROPERTIES OF CEMENT MORTAR

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ABSTRACT

Coal combustion by-products (CCPs) have been around since man understood that burning coal generates electricity. The concept of sustainable development only reawaken our consciousness to the huge amount of CCPs around us and the need for proper reutilization than the current method of disposal which has severe consequences both to man and the environment. Coal bottom ash (CBA) is formed in coal furnaces. It is made from agglomerated ash particles that are too large to be carried in the flue gases and fail through open grates to an ash hopper at the bottom of the furnace. Bottom ash is mainly comprised of fused coarser ash particles. These particles are quite porous and look like volcanic lava. Bottom ash forms up to 25% of the total ash while the fly ash forms the remaining 75%. One of the most common uses for bottom ash is as structural fill. This thesis presents the result of utilization of waste from thermal power plants to improve some engineering properties of concrete. Effect of coal bottom ash on the properties of cement mortar such as workability, chemical characteristics and pozzolanic activity are presented. Coal bottom ash (CBA) were utilized in partial replacement for fine aggregates and cement respectively in the range 10%, 20% and 30%. Kapar coal bottom ash satisfies the requirement of ACI 213 for fine lightweight aggregate because it has 100% passing the No.4 sieve size (5μm). The result of compressive strength and degree of hydration shown the 10% replacement has the highest pozzolanic activity due to hydration processed. The workability using bottom ash replacement showed that bottom ash has much higher water absorption ratio as compared to the natural sand since the workability decreased with the increasingly of bottom ash replacement. The XRF testing shown the bottom ash is safely to be used since this material is not harmful and classified as a pozzolanic material. As a conclusion, the presence of bottom ash as sand replacement in cement mortar increased the quantity of water. The weak microstructure obtained with the use of bottom ash is responsible for the decrease in compressive strength.

ABSTRAK

Penghasilan sisa arang batu melalui pembakaran (CCPs) telah wujud semenjak manusia memahami bahawa pembakaran arang batu boleh menjana tenaga elektrik. Konsep pembangunan yang berterusan telah menimbulkan kesedaran masyarakat terhadap jumlah sisa terbuang daripada CCPs dan keperluan untuk digunakan semula daripada dilupuskan, apabila kaedah pelupusan sedia ada memberi kesan kepada manusia dan alam sekitar. Abu dasar arang batu (CBA) terbentuk di dalam relau arang batu semasa pembakaran. Ia terhasil daripada zarah abu yang bercampur dan terlalu besar untuk melalui gas serobong dan gagal melalui jeriji yang terbuka kepada corong abu di bahagian bawah relau. Abu dasar arang batu kebiasaannya terdiri daripada zarah abu kasar. Zarah zarah ini kebiasaanya agak poros dan kelihatan seperti lava gunung berapi. Kebiasaanya, 25% hasil pembakaran membentuk abu arang batu manakala 75% menghasilkan debu arang batu. Salah satu kegunaan abu arang batu adalah sebagai penimbus struktur. Kajian ini membentangkan hasil daripada penggunaan bahan buangan dari loji kuasa untuk menambah baik beberapa sifat kejuruteraan konkrit. Kesan daripada penggunaan abu dasar arang batu terhadap sifat simen mortar seperti kebolehkerjaan, ciri ciri kimia abu arang batu dan pozzalana aktiviti dibincangkan. Abu arang batu digantikan dengan pasir sebanyak 10%, 20% dan 30%. Abu dasar arang batu dari Kapar Energy memenuhi keperluan ACI 213 untuk agregat ringan kerana melepasi 100% saiz ayak No.4 (5μm). Hasil kekuatan mampatan dan tahap penghidratan menunjukkan penggantian sebanyak 10% mempunyai aktiviti pozzolana tertinggi akibat daripada proses penghidratan. Kebolehkerjaan simen mortar menunjukkan bahawa abu arang batu mempunyai tahap penyerapan air yang lebih tinggi berbanding pasir kerana kebolehkerjaan menurun dengan penggantian abu arang batu. Ujian XRF menunjukkan bahawasanya abu arang batu selamat digunakan kerana bahan ini tidak merbahaya dan diklasifikasikan sebagai bahan pozzolana. Kesimpulannya, penggunaan abu dasar arang batu sebagai pengganti pasir di dalam simen mortar meningkatkan kadar penggunaan air. Mikrostruktur abu dasar arang batu yang lemah bertanggungjawab untuk penurunan dalam kekuatan mampatan.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
ACI	American Concrete Institute
BS	British Standard
MSW	Municipal Solid Waste
MS	Malaysian Standard

CHAPTER 1

INTRODUCTION

1.1 Introduction

The electricity industry, particularly coal-fired power plants, has been greatly affected by the increasing public attention being paid to the environment. Coal ash generated from power plants have become an important economic and environmental objectives, and thus calls for recycling alternatives to traditional option due to high generation amount of low recycling rate (Kurama. H & Kaya. M, 2007).

The coal ash collected at bottom of furnace is called bottom ash. Bottom ash particles are physically coarse, porous, glassy, granular and grayish in colour. According to Malkit and Rafar (2012), bottom ash particles forms up to 25% of the total ash while fly ash forms the remaining 75%. Bottom ash along with unutilized fly ash is disposed off in ponds spread over acres of land. The limited availability of land for landfills and the possibility of utilization of the energy in the waste water are two of the major reasons for incinerating municipal solid waste (MSW) instead of landfilling it (Stegemann et al, 1995).

Environment concerns are increasing day by day and land fill space is declining, therefore it becomes essential to initiate the effort to utilize the bottom ash. Bottom ash has the appearance and particle size distribution similar to the natural fine aggregate i.e river sand (Malkit & Rafar, 2012). Owing to the fact that in many areas of the world there exists a shortage of natural aggregates, the utilization of ash produced in power generation plants is receiving increased attention (White & Case, 1990).

1.2 Problem Statement

Municipal Solid Waste (MSW) management is gaining importance both in developed and developing countries, particularly those with high population density (Demirbas, 2011). The main goal of management is to implement and coordinate activities such as collection of sorted waste, reduction, reuse, recycling and disposal in order to minimize the MSW environmental impact and to ensure a sustainable development.

Bottom ash is produced in power generation plants as a by-product from the burning of coal. It is usually treated as a waste product which, in many instances, is required to be disposed of in the same manner as municipal waste (Kayabali & Bulus, 1999). As a result, it is predictable that the discovering the utilization of this material in any type of material making process would be able to reduce quantity of waste thrown (Haldun & Mine, 2007).

1.3 Objective of the Study

The objectives of the study are:

i. To determine the chemical characteristic of bottom ash as a sand replacement on the cement mortar.
ii. To investigate the effect of bottom ash towards workability.
iii. To investigate the effect of bottom ash as a sand replacement towards pozzolanic activity.

1.4 Scope of the Study

Based on the objectives that have been listed, this study is concentrated on investigation of cement mortar using coal bottom ash (CBA) as a fine aggregates replacement. In order to determine the strength of cement mortar, the mortar mixes will be designed for constant grade follows designation C1329-04 and C109/C 109M-07.the plain cement mortar formulation is compose of cement and sand without addition of coal bottom ash.

This waste product was taken from Kapar Energy, Stesen Jana Elektrik, Sultan Salahuddin Abdul Aziz, Selangor. The bottom ash then was crush into the required size using crusher machine which is the suitable size to make this mixture passing 5mm and will be sieve to it required fine aggregate size. The normal cement mortar will be stand as the control mixture. The paste will be casted and poured into mould and the hardened sample was taken out from mould after 24 hours. Then, the hardened sample specimens were cured in water for 7 and 28 days for all mixes.

In the other hands, the testing for the mortar involves the mix design test. The objective of this test is to understand the material have been used in concrete design and the implication on the workability and strength of concrete including chemical characteristics of the material used. The reference standard for this test is C109/C 109M-07.

Furthermore, there are 24 samples of mortar block 50mm x 50mm x 50mm are design in this study which is three for 7th days and three for 28th days of the curing day. For each samples, there are three samples of concrete were prepared for the average.

Table 1.1 : Cement mortar composition

No. of sample	Composition of mixing	
	Natural Fine Aggregate	**Coal Bottom Ash**
Control	100%	0%
1	90%	10%
2	80%	20%
3	70%	30%

1.5 Significant of the Study

The purpose of the study are :

i) Reduce the usage of sand by replacing bottom ash as a sand replacement in cement mortar properties.

ii) To reduce waste municipal solid waste

iii) To determine the chemical characteristics of bottom ash as a sand replacement in the cement mortar properties.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Bottom Ash

Bottom ash is produced in power generation plants as a by-product from the burning of coal. It is usually treated as a waste product which, in many instances, is required to be disposed of in the same manner as municipal wastes. A great portion of industrial wastes is composed of power plant ashes, that is, fly ash and bottom ash (Kayabali. K & Bulus. G, 1999).

Nowdays, in utilizing such low-quality coal it should be realized that increasing amounts of ash are being handled and disposed of. Coal is pulverized and burned in a grate boiler. Fly ash is collected in a proportion of 60% and is easily valorised in concrete and cement production (Cheriaf. M, Rocha. J & Pera. J, 1999). According to Malhotra et al also, the remaining 40% of coarser ash falls down on a belt conveyer to be milled and water-cooled before transportation to a lagoon. This type of ash is called 'bottom ash' in the present study and has been investigated for its potential pozzolanic properties. Until has no now, it has not yet been valorised in the cement industry.

2.1.1 Municipal Solid Waste (MSW)

As expected, incineration become a major municipal waste management alternative as it is not only effective in term of waste volume reduction, but can also produce benefits in term of energy recovery. However, municipal solid waste incinerator ash is piling up at incinerator facilities and has become the source of other type of environmental issues. 90% of the total amount is bottom ash and 10% is fly ash. Mineralogical studies have found that MSWI bottom ash is composed of equal amounts of fine ash material and small quantities of crystallized, metallic components, ceramics (Reginders, 1995).

Several studies have reported the danger that arises due to heavy metal during the handling and disposal of fly ash and coal bottom ash obtained as a by product of mineral coal combustion (Polic. P.S, Illic. M.R and Propovic. A.R, 2005).

2.1.2 Characteristic of the Bottom Ash

Significant amounts of waste coal ashes are produced during combustion of coal in thermal power plants. For ecological and economical reasons, there is intensive research to find ways of increasing the use of these waste materials, especially if they can be utilized in bulk, such as for sub-base and base materials for road construction (Prvoslav D et al, 2010). Two kinds of coal ashes are distinguished are fly ash (FA) and bottom ash (BA). There are three principal differences between them :

a) The content of the oxides are SiO_2, Al_2O_3 and Fe_2O_3 are greater in FA, which consequently may exhibit pozzolanic properties, but BA is a more or less inert material, examples bottom ash usually does not exhibit pozzolanic properties.
b) FA has a lower unburned carbon (coal) content.
c) FA consists of finer (powdery) particles than BA, the particles of which are coarse (sized between sand and gravel). Fused and with a glassy texture.

State by Prvoslav D et al, according to the mentioned characteristics, FA could be applied as a partial substitute for Portland Cement (PC) and BA has been used as the entire source of aggregate (sand and gravel) in road construction. The content of unburned carbon in the ashes is an important factor for their applicability in road construction. Bottom ash, with a higher content of unburned carbon, has a more porous and vesicular texture and consequently is crushed more easily under compacting and loading.

2.1.3 Classification of the Bottom Ash

Incinerator Bottom Ash (IBA) is a heterogeneous material consisting of ash, metal items and inert component such as glass. It can be classified as non-hazardous waste or hazardous waste depending on the outcome of an assessment against 15 hazard properties (Environment Services Association, 2012). The bottom ash in Class F contain the sum of SiO_2 + Al_2O_3 exceed 70% and according to ASTM C618 this can be attributed to the use of Bituminous or Anthracite Coal which produce low calcium content (Muhardi et al., 2010). Bottom ash in Class C is generated from the combustion of Lignite or Sub-bituminous coal with a high calcium content. The sum of SiO_2 + Al_2O_3 is less than 70% but greater than 50% (Nagathan et al., 2012).

2.1.4 Chemical Properties

According to Muhardi et al the major components of the three thermal power plants bottom ash in Malaysia studied were Silica, Alumina and Iron Oxide with percentage compositions of 9.78 – 49.4%, 20.75 – 23% and 17-13% respectively.

Table 2.1 : Chemical composition of OPC, bottom ash, fly ash & requirements

Chemical Contents	Naganathan et al.,(2012)	Muhardi et al,. (2010)		Awang et al,. (2010)		ASTM C618 Requirement on the use of the fly ash.
	Ordinary Portland Cement	Coal Bottom Ash (%)	Fly Ash (%)	Coal Bottom Ash (%)	Fly Ash (%)	
SiO_2	21.5442.7	42.7	51.80	46.60	47.10	$SiO_2 + Al_2O_3$
Al_2O_3	5.32	23.0	26.50	26.10	30.00	$+ Fe_2O_3 > 70$
Fe_2O_3	3.60	17.0	8.50	12.40	7.34	Class 'F'
CaO	63.60	9.80	4.81	8.31	7.21	> 10 class'C'
K_2O	-	0.96	3.27	1.34	1.62	-
TiO_2	-	1.64	1.38	1.84	1.83	-
MgO	1.00	1.54	1.10	1.26	1.52	Max 5.0
P_2O_5	-	1.04	0.90	0.62	1.37	-
Na_2O	-	0.29	0.67	0.62	0.72	Max 1.5
SO_3	2.10	1.22	0.60	0.30	0.32	Max 5.0
BaO	-	0.19	0.12	0.13	0.27	-
MnO	-	-	-	-	-	-
ZnO	-	-	-	-	-	-
SrO	-	-	-	0.19	-	-
CO_2	-	-	-	0.10	0.10	-
Gs	3.15	1.99	2.30	2.39	2.19	-

Smaller percentages of potassium, magnesium and sodium are also present in Malaysia power plant bottom ash with traces of barium, manganese and zinc. BS 3892: Part 1: 1993 specified an SO_3 content of less than 2.5% and a maximum of 5.0% by ASTM C618 and Na_2O alkali of not more than 1.5%.

2.1.5 Heavy Metal of Bottom Ash

The emission and management of heavy metals from MSWI have been studied extensively because of the regulations and also issues with the environment (Wiles, C.C., 1996). For example, the particle size distributions of Zn. Pb, and Cu were in bimodal forms and mass concentration in each fraction of the particle size was in descending order of Zn, Pb, Cu in the stack of scale MSWI (Chang M.B., 2000). Yoo et al concluded that more volatile metals such as Cd, Pb and Zn showed higher enrichment in the particular matter (PM) emitted through stack instead of bottom ashes. Cu, Pb and Zn associated with PM smaller than 2.5mm accounted for approximately 90% of the total mass of each metal in PM10. Lithophilic metals such as Fe, Cu, Cr and Al remained mainly in the bottom ash while Cd volatilized from the furnace and condenses and present in fly ash.

The bottom ash must be carefully managed. Bottom ash is a highly heterogeneous burnt-out mixture of slag, ferrous and non-ferrous metal, ceramics, glass, other non-combustibles and residual organics matter. The major elements in bottom ash are O, Si, Fe, Ca, Al, Na, K and C (Wiles, C.C., 1996). Moreover, many metals in the bottom ash are in the form of metallic oxides. Bottom ash thus presents a similar composition of natural geological material (Chimenos et al, 1999).

From the Table 2.2 below, if the concentrations are below these limits, wastes are considered as inert and can be deposited along with municipal wastes in municipal waste landfills. If the concentrations are within these limits, wastes are considered non-hazardous and must be deposited in special cell (monolifts) in municipal waste landfills. But, if the concentrations are within or higher than these limits, waste are considered hazardous. If the concentrations are within the limits, the wastes must be deposited in hazardous waste landfills. If the concentrations is higher than the upper limits, wastes cannot be deposited in any way. They must be incinerator or treated to reduce the concentrations before disposal (Veli et al., 2007).

Table 2.2 is the concentration of parameter determined in bottom ash from the previous study by Veli et al., 2007.

Table 2.2 : The Concentration of Parameters Determined In Bottom Ash

Parameters (mg/l)	**Bottom Ash**		
	Rangers	**Means**	**Standard Deviation**
AOX	0.014 – 1.879	0.404	0.59
Pb	< 0.021 – 0.132	0.064	0.031
Cd	< 0.0009 – 0.04	0.019	0.019
Cr (VI)	< 0.007 – 0.685	0.052	0.159
Cu	< 0.002 – 0.4718	0.1057	0.128
Ni	< 0.0037 – 0.3848	0.0474	0.088
Hg	< 0.0048 – 0.0598	0.0134	0.014
Zn	0.0031 – 1.511	0.1975	0.359
As (III)	< 0.0276 – 0.031	0.029	0.002
Cl^-	70 – 380	177.86	98.15
CN^-	0.0019 – 0.059	0.011	0.016
SO_4^{2-}	1320 – 2040	1676	216.82

Table 2.3 : Maximum Permitted Contents After batch Tests (L/S 2). General Permit for NKAB to Use Coal Bottom Ash from Grate Firing.

Table 2.3 : Maximum Permitted Contents After batch Tests (L/S 2). General Permit for NKAB to Use Coal Bottom Ash from Grate Firing

Parameter	Unit	Guideline	Limit
pH		6.5 – 10	5 – 11
Conductivity	mS/m	100	300
Chloride	mg/l	300	1000
Sulphate	mg/l	300	1000
Aluminium	µg/l	300	2000
Arsenic	µg/l	20	100
Cadmium	µg/l	5	30
Chromium	µg/l	50	300
Copper	µg/l	100	1000
Nickel	µg/l	100	500
Lead	µg/l	50	500
Zinc	µg/l	100	1000

2.2 Ordinary Portland Cement

2.2.1 General

According to BS12:1996, cement is hydraulic binder. It is finely ground inorganic material which, when mixed with water will form a paste which set and hardens by mean of hydration and process and which after hardening will retains its strength and stability even under water.

Portland cement type I (BS 12:1978), is the most used in construction up until now a day. It also calls Ordinary Portland Cement. This OPC only can be used in normal construction that does not have any sulphate attack or groundwater (Abu Bakar A. F., 2012).

2.2.2 Chemical Composition of Portland Cement

Portland cement mostly contained limestone or chalk, alumina, and silica found as clay or shale. Generally, chemical contaion of Portland cement is showed in Table 2.1, which is give interval limitation of oxide in Portland cement.

Table 2.4 : Estimate Interval Limitation of Portland Cement

Oxide	Percentage (%)
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-0.6
MgO	0.1-4.0
SO_3	1-3
Alkali	0.2-1.3

Generally, high lime content in Portland cement can increase the setting time but lime can give a high early strength. Increasing of silica contain also can increase the setting time and increase the strength. In the other hand, increase alumina tends to reduce setting time but also increase strength.

2.2.3 Hydration Process

When cement is exposed to water, chemical reactions begin to take place. These reactions are called hydration process, which in return will produce a firm and hard mass. In these reaction, it is of interest to know whether the hydration products contribute to the strength of hydrated cement (Mindess and Young, 1981).

$$\text{(Cement) } CaO + H2O \longrightarrow C - S - H + Ca(OH)_2 \qquad (1.1)$$

In the early stages, gypsum will react to control the setting tome and the reaction that takes place is exothermic. For the first 14 days, the strength of concrete is provided by C_3S and C_2S contribute equally to ultimate strength. C_3S have high early strength but does not contribute significant to the ultimate strength and is prone to sulphate attack. C_4AF only gives a small effect on the strength of concrete (Zakaria, 1987).

2.3 Aggregates

Aggregates are defined as mineral constituents of concrete in granular or particulate form, usually comprising both coarse and fine fractions (Alexender M., Mindess S., 2005). Aggregates a granular material obtained by processing natural material (BS 882:1992).

Aggregates is relatively inexpencive and does not enter into complex chemical reactions with water, it has been customary, therefore, to treat it as an inert filler in concrete (Mehta, 2006). Aggregate in concrete can be divided into fine and coarse aggregate. Fine aggregate is represented by sand which supply much more than coarse aggregates. Fine aggregate mainly passing a 5.0μm sieved and containing no more coarser material than is permitted for the various grading (BS 882:1992).

The properties of aggregate that most important to engineers, since the performance of concrete will depend to some degree on these aggregate properties for example the parameter related to fracture, stiffness and resistance to abrasion (Alexander M., Mindess S., 2005).

2.3.1 Size Distribution

Generally, a series of successive crushers are used, with oversize particle being returned to the respective crusher to achieve desirable grading. The best particle distribution shape is usually achieved by primary crushing and then secondary crushing, but from an economic point of view, a single crushing process usually most effective. Primary crushing usually reduces the C&D concrete rubble to about 50mm pieces and on the way to the second crusher, electromagnet is used to remove any mates impurities in the material (Corinaldesi et al., 2002). The particle shape analysis of recycled aggregate indicates similar particle shape on natural aggregate obtained from crushed rock. The recycled aggregate generally meets all the standards requirements of aggregate used in concrete.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discussed in detail the procedure in carrying out the experimental work and laboratory test to achieve the objective as set in this project. There is a variety of testing to be carried out in this project. Sieve analysis is the first test to be carried out to testing the replacement material which is coal bottom ash as a sand replacement. Flow table will be conducted to determine the workability of the cement mortar. Then, the testing will be follow by compressive strength for the specimen strength. For determined the chemical characteristic, X-Ray Fluorescence (XRF) and Scanning Electron Microscopy (SEM) test will be conducted in central laboratory. Degree of reaction was conducted to determine the pozzolanic activity.