STRENGTH AND WATER PERMEABILITY OF CONCRETE CONTAINING COAL BOTTOM ASH AS CEMENT AND FINE AGGREGATE REPLACEMENT MATERIAL

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DEDICATION

Alhamdulillah, all praises to Allah,

for give me a good health and strength while making this thesis.

For my late father, beloved mother and husband,

For the sake of raising me up and loving me;

to more that I can be

For the love and the care

I just want you to know that I LOVE YOU;

you have my words.

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ABSTRACT

The reuse of industrial waste as a substitute of concrete ingredents presents an alternative solution for minimizing waste and producing sustainable concrete construction. However, coal bottom ash (CBA) is the one of the major waste product, generated by coal operated thermal powerplants. Therefore, study aims to utilization of grinded coal bottom ash (GCBA) and ungrinded coal bottom ash (UGCBA) as a cement and fine aggregate replacement material in concrete and evaluate its strength and durability performance. In this study, GCBA was grinded for 20, 30 and 40 hours to produce fine particles as comparable to cement. Initially, particle size distribution (PSD) analysis and X-ray Fluorescence (XRF) analysis were carried out to evaluate the particles characteristics before and after grinding .The 20% GCBA produced through 30 hour grinding period was considered as optimum percentage based on 28 day compressive strength. Then, the concrete specimens were incorporated 20% GCBA as cement replacement and varying proportion of fine aggregate were replaced with UGCBA at 5%, 10%, 15% and 20% by weight of fine aggregate. Afterward, compressive strength and water permeability tests were evaluated at 7, 28, 56, 90 and 180 days respectively. It was observed that concrete containing GCBA and UGCBA for all percentage replacement were found to be higher compressive strength and water permeability coefficient as compared to the control concrete. However, it was noticed that lower compressive strength and higher value of water permeability coefficient compared to control samples after 90 days up to 180 days. Besides that, at the age of 180 days it was also observed that concrete containing more than 20% replacement of fine aggregate gives the lower compressive strength as compared to control mix concrete. Hence, it can be concluded that 20% replacement of cement with GCBA was found to be effective for improvement of compressive strength and reduction in water permeability. This study declared that compressive strength decreases and water permeability increases when optimum GCBA incorporated with UGCBA in concrete.

ABSTRAK

Penggunaan semula bahan buangan industri sebagai pengganti percanggahan konkrit memberikan penyelesaian alternatif untuk meminimumkan sisa dan menghasilkan pembinaan konkrit yang tahan lasak. Walau bagaimanapun, abu bawah arang batu (CBA) adalah salah satu daripada produk sisa utama, yang dihasilkan oleh janakuasa haba yang dikendalikan arang batu. Oleh itu, kajian ini bertujuan untuk memanfaatkan GCBA dan UGCBA sebagai simen dan bahan gantian agregat halus dalam konkrit dan menilai kekuatan dan daya tahannya. Dalam kajian ini, GCBA telah digiling selama 20, 30 dan 40 jam untuk menghasilkan zarah halus sebagai setanding dengan simen. Pada mulanya, analisis pengedaran saiz zarah (PSD) dan analisis X-ray Fluorescence (XRF) dijalankan untuk menilai ciri-ciri zarah sebelum dan selepas pengisaran. Namun, 20% GCBA yang dihasilkan melalui tempoh pengisaran 30 jam dianggap sebagai peratusan optimum berdasarkan Kekuatan mampatan 28 hari. Kemudian, spesimen konkrit dimasukkan 20% GCBA kerana penggantian simen dan pelbagai agregat halus digantikan dengan UGCBA pada agregat denda 5%, 10%, 15% dan 20% berat. Selepas itu, ujian mampatan kekuatan mampatan dan air dinilai pada 7, 28, 56, 90 dan 180 hari masing-masing. Telah dilihat bahawa konkrit yang mengandungi GCBA dan UGCBA untuk semua penggantian peratusan didapati lebih tinggi kekuatan mampatan. Walau bagaimanapun, diperhatikan bahawa kekuatan mampatan yang lebih rendah dan nilai yang lebih tinggi daripada pekali kebolehtelapan air berbanding dengan sampel kawalan selepas 90 hari sehingga 180 hari. Selain itu, pada umur 180 hari juga diperhatikan bahawa konkrit yang mengandungi lebih daripada 20% penggantian agregat halus memberikan kekuatan mampatan yang lebih rendah berbanding dengan konkrit campuran kawalan. Oleh itu, dapat disimpulkan bahawa penggantian simen 20% dengan GCBA didapati berkesan untuk meningkatkan kekuatan mampatan dan pengurangan kebolehtelapan air. Kajian ini menyatakan bahawa kekuatan mampatan berkurangan dan kebolehtelapan air bertambah apabila optimum GCBA digabungkan dengan UGCBA dalam konkrit.

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LIST OF ABBREVIATION

ASTM	American Society For Testing And Materials
BS EN	British Standard
CBA	Coal Bottom Ash
CIDB	Construction Industry Development Board
CSH	Calcium Silicate Hydrate
GCBA	Grinded Coal Bottom Ash
PSD	Particle Size Distribution
PSA	Particle Size Analyzer
SEM	Scanning Electron Microscopy
UGCBA	Ungrinded Coal Bottom ash
XRD	X-ray Diffraction
XRF	X-ray Fluoresence

LIST OF SYMBOL

A	Surface area of specimen (mm)
Al_2O_3	Aluminium oxide
$Ca(OH)_2$	Calcium hydroxide
C_3A	Calcium Aluminate
CaO	Calcium oxide
CO_2	Carbon dioxide
d	depth of water penetration (m)
Fe_2O_3	Iron oxide
f_{ct}	Compressive strength (N/mm^2 or MPa)
h	hydraulic head of water (m)
Kp	Coefficient of water permeability (m/s)
m	mass (g)
P	Maximum indicated load (N)
SiO_2	Silica oxide
t	time under pressure (s)
p	density of water ($1000kg/m^3$)
U	porosity of concrete

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CHAPTER 1

INTRODUCTION

1.1 Study background

Nowadays, application of concrete in the construction still becomes a choice among the contractor compared to steel. This is due to its properties which have higher strength, quality and durability (Sharma & Kumar, 2015). The huge consumption of concrete causes the demand of cement and fine aggregate increaseded gradually, thus leading towards environmental concequences. Realising this situation, Construction Industry Development Board (CIDB) has introduced some policies as to utilize waste materials to produce fresh concrete such as fly ash (FA), coal bottom ash (CBA), waste foundry fine aggregate (FS), slag, silica fume, and waste glass (Dwikojuliardi, 2016). In particular, utilisation of industrial waste products could be an appropriate solution not only for the sustainable development in terms of minimising environmental pollution and in order to deal with the blooming concern of carbon dioxide (CO_2) production (Mangi *et al.,* 2018).

The burning of coal in thermal power plant produces two types of major wastes namely fly ash (FA) and Coal Bottom Ash (CBA). However, CBA is coarser in size and utilized as landfilling material and base material in road construction. Besides that, CBA has a good pozzolanic potential which is attributed to the presence of Silica oxide (SiO_2) and Alumina oxide (Al_2O_3). It reacts with calcium hydroxide during cement hydration, to form additional Calcium Silicate Hydrate (CSH) and Calcium Aluminate Hydrate (CAH) could effectively form denser matrix leading towards higher strength and better durability of concrete. In this study, CBA was used as cement and fine aggregarte replacement material to produce concrete. CBA that was collected at the bottom of furnace on burning of coal in furnace of coal fired thermal power plants was partially replaced with fine aggregate and after grinding process it was replacement with cement to prepare concrete. The quality of concrete partially made of CBA as fine aggregate and cement were determined by workability, strength and durability (Neville, 2004). However, it was found that compressive strength decrease in strength with CBA due to the porous surface and very rough particles structure which makes this material less durable (Bajare, Bumanis & Upeniece, 2013).

In order to overcome the problem associated with particle size and shapes of CBA, grinding process could be a solution to make it powdered form as it can be utilized as cement replacement material. Therefore, the utilization of industrial wastes like coal bottom ash could reduces the environmental impact. Considering the sustainability and durability point of view, it is need of time to established new cement replacement materials for the production durable concrete (Ramadhansyah *et al.*, 2012). However, an adequate grinding process could improves the pozzolanic activity of the CBA (Cheriaf *et al.*, 1999). The ability of CBA to function as filling role causes the 28-day strength index of ash increases by 27% when it is ground for 6 hours in laboratory ball mill. Venkatanarayanan & Rangaraju (2015) investigated the effectiveness of grinding CBA as a cement replacement through setting time, microstructure, strength and durability of concrete. Based on the results, they suggest that the use of CBA as a cement replacement to finer fraction can improve the performance of concrete. The internal porosity created by coarse ash in the matrix and their inability to completely participate pozzolanic reaction of grinding ash may be the factor for poorer performance compared to the grind ash. Furthermore, the grinded ash mixture revealed denser microstructure compared to the control mixture and slightly improves all the properties.

In this study, GCBA was produced and incorporated as a cement replacement material in concrete mix to increase the performance of concrete containing ungrinded coal bottom ash (UGCBA) as fine aggregate particularily compressive strength and durability. Therefore, durability of concrete containing GCBA and UGCBA were evaluated in terms of water permeabilityThe primary objectives of this study is to eveluated influence of GCBA as cement and UGCBA as fine aggregate replacement in concrete. In addition to that, the beneficial effects of grinding GCBA on the properties of concrete were studied by the performance of concrete mixtures containing the optimum GCBA and UGCBA.

1.2 Problem statement

In Malaysia, Coal Bottom Ash (CBA) is a waste produced by the coal based power plants due to burning of coal for the generation of electricity. However, this huge waste is being directly disposed to the landfills which could decreases the landfill capacity and contribute to environmental issues in the long term. The huge amounts of CBA waste, somehow gives negative impact to environment and human. The government needs to allocate more hectares of landfill for disposal and spends a lot of money for transporting the waste and also maintenance purposes. However, recycling of such waste could reduce the solid waste as well as to ensure the environment sustainability.

Recently, many studies have been conducted on CBA as a construction material which has brought many benefits to the concrete construction due to its low cost construction material. Previously, CBA was commonly used to replace fine aggregate in concrete due to its coarser particle size. However, it also poses pozzolanic characteristics like other ashes such as fly ash, rice husk ash, and palm oil fuel ash.. The physical characteristics of CBA shows the similar size like fine aggregate and larger than cement and high porosity causing water to penetrate easily (Bajare *et al.,* 2013). The formation porosity created by the coarse ashes size in the concrete and their inability to completely participate in pozzolanic reaction that could be a the reasons for the poorer performance of compressive strength. To overcome the problem associated with particle size and shapes of CBA, a few studies were reported on incorporation of very small size of CBA by increase the surface area (Awang *et al.,*2012). It was also previously declated thatfine CBA has good pozzolanic properties (Zainal Abidin *et al.,* 2014). The work of Kim *et al.,* (2015) shows that the ungrinded and ground mixtures performed better than the control mixtures in all tests conducted. Therefore, the effect of grinded coal bottom ash (GCBA) as cement replacement and ungrinded coal bottom ash (UGCBA) as a fine aggregate replacement on the performance of concrete were conducted in this study. Considering the gap of study, the objectives has been set forward to determined the optimum percentage replacements of GCBA Then, the performances of concrete containing optimum proportion of GCBA as a cement replacement with varying proportions of UGCBA as fine aggregate replacement were evaluated in terms of compressive strength and water permeability of concrete.

1.3 Objectives

In this research, a study has been carried out on the grinded coal bottom ash (GCBA) and ungrinded coal bottom ash (UGCBA) in concrete as cement and fine aggregate replacement. GCBA was grinded at period 20, 30 and 40 hours. This research was carried based on three main objectives. The detailed objectives are outlined below.

a) To characterize the physical and chemical characteristics of GCBA and UGCBA.
b) To determine an optimum content of GCBA with 20, 30, 40 hours time through compressive strength.
c) To investigate the influence of GCBA concrete in optimum percentage with addition of UGCBA on the compressive strength and water permeability of concrete.

1.4 Scope of study

The scopes for this study can be divided and described in the following stages :

a) Preparation of material

The coal bottom ash (CBA) collected from power plant was oven dried and then was grinded by LA Abrasion machine at 1 hour. Then the CBA was divided into two parts. First part, CBA was sieve into 5mm siever. Passing 5mm coal bottom ash obtained is used as replacement of fine aggregate and known as Ungrinded coal bottom ash (UGCBA). Second part was used as cement replacement material. The CBA after grinded for 1 hour was sieve into 600 micro sieves then milling by using

Ball Mill at 20 hours, 30 hours and 40 hours and it is named by grinded coal Bottom ash (GCBA). Another raw material used for present study is cement, fine aggregate, course aggregate and water.

b) Characterisation material

For UGCBA the tests that were conducted are sieve analysis and specific gravity. For GCBA the test that conducted includes Particle size distribution (PSD) using particle size analyzer, setting time, specific surface area, specific gravity and X-Ray Fluoresence (XRF).

c) Optimisation of GCBA and GCBA-UGCBA concrete

At the first phase, the optimisation percentage of GCBA was assessed by determining the higher GCBA concrete compressive strength at 28 days. The percentage replacements of GCBA for each grinding time (20 hour, 30 hour and 40 hour) used in present study are 10%, 20% and 30%. The second phase involves the optimisation of GCBA combining with different replacement percentage of UGCBA of 5%, 10%, 15 % and 20%. There were two tests were conduct for the hardened concrete containing optimisation grinded GCBA-UGCBA concrete. There were compressive strength and water permeability test. The compressive strength and water permeability by using cube sample (100mm x 100mm x 100mm and 150mm x 150 mm x 150 mm). The method curing applied for this study is wet curing by submerging the sample in a water tank 7, 28, 56, 90, and 180 days.

1.5 Significance of study

Cement based material is the most important construction material. However, it facing issues of productivity, economy, quality and environment. Concrete has to combine with other material such as bottom ash to reduce the waste material. The replacement of bottom ash in concrete can been seen as a good alternative to reduce the waste material from coal, reduce cost of concrete and as well as reducing the impact on environment pollution. Concrete containing bottom ash meet the requirement for sustainable development approach. Direct use of these materials in construction projects consuming large volumes of materials, such as highway embankment construction, not only provides a promising solution to the disposal problem, but also an economic alternative to the use of traditional materials. The utilization of bottom ash in construction projects can save energy, reduce the need to mine virgin materials, and reduce costs for both producers and end users.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete is the product contains cement, water, fine aggregate and course aggregate (ASTM C125). Nowadays, concrete outperforms all other construction materials worldwide. However, the manufacturing process of cement has taken a toll on environment and health due to the increasing issues of pollution and also harmful effect to the human health. Considering the environmental pollution many sstudies have been given attention towards the utilization of waste products to produce new cement replacement material for construction production. However, coal bottom ash (CBA), fly ash (FA) and silica fume (SF) have been identified as a suitable replacement of cement and fine aggregate. With the application of these waste materials specifically CBA as a replacement material of cement and fine aggregates. It is expected that this approch could resolve the environmental and health issues associated with the use of ordinary Portland cement in concrete construction. Thus, this chapter discussed thoroughly the characterisation of a cement and fine aggregate in concrete. A general literature review of existing studies were carried out specifically on CBA as a cement and fine aggregate replacement material in concrete have been reported in this chapter.

2.2 Cement

Cement is the most demand material in the world. The demand of cement material

Cement is the most demanding material in the world. The demand of cement has been continuously increasing as the growing industrial activities which involving concrete construction such as roads constructions, building and bridges etc. According to Bajare *et al.*, (2013) cement defined as the dry powder and this powder transforms into a cement paste once mixing with water. In 1824, Joseph Aspdin, a brick layer took out a patent on a hydraulic cement that he called portland cement because its color resembled the stone quarried on the Isle of Portland. Cement is manufactured through a closely controlled chemical combination of calcium, silicon, aluminum, iron and other ingredients. Portland cement is the basic ingredient of concrete.

Concrete is formed when Portland cement creates a paste with water that binds with fine aggregate and rock to harden.Cement mixed with water causes a chemical reaction and forms a paste and hardens to bind individual structures of building materials used to make concrete as well as mortar. Concrete is made of cement, water, fine aggregate, and gravel mixed in definite proportions, whereas mortar consists of cement, water, and fine aggregate. Portland cement is suitable for wet climates and can be used underwater. There are different types of Portland cement include Portland blast furnace slag cement, Portland fly-ash cement, Portland pozzolan cement, Portland-silica fume cement, masonry cement, and white blended cement (Tariq *et al.*, 2017) . There are eight major ingredients of cement. Table 2.1 and Table 2.2 are showing the ingredients of cement and the general percentage of these ingredients in cement (Elena & Lucia, 2012).

The physical and chemical characteristics of good cement are like fineness of cement, setting time and specific gravity could be the influencing perameters that gives an effect on performance of fresh and hardened concrete. Some descriptions about cement properties such as physical characterization and chemical characterization were explain in details in the following section.

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