BOTTOM ASH EFFECT IN PORTLAND CEMENT COMPOSITE PERFORMANCE

by

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
ASR	Alkali Silica Reactivity
BA	Bottom Ash
BACC	Bottom Ash Cement Composite
CASH	Calcium Aluminate Silicate Hydrates
CO_2	Carbon Dioxide
CSH	Calcium Silicate Hydrate
DEF	Delayed Ettringite Formation
EDX	Energy Dispersive X-ray Spectroscopy
FTIR	Fourier Transform Infrared Spectroscopy
K	Potassium
OPC	Ordinary Portland Cement
PAI	Pozzolanic Activity Index
SCM	Supplementary Cementitious Material
SEM	Scanning Electron Microscope
UniMAP	University Malaysia Perlis
USA	United States of America
XRD	X-ray Diffraction
XRF	X-ray Fluorescence

KESAN ABU BAWAHAN DALAM PRESTASI KOMPOSIT SIMEN PORTLAND

ABSTRAK

Matlamat utama kajian ini adalah untuk mengkaji keberkesanan abu bawahan dalam simen Portland untuk meningkatkan sifat simen. Kesusasteraan yang terhad berhubung dengan penggantian abu bawahan ke dalam simen Portland menyebabkan siasatan yang teliti agar dapat digunakan dengan meluas untuk mencapai prestasi simen yang ada dalam industri pembinaan. Tiga jenis zarah saiz partikel (63, 75, 150 μm) dan kesan penggunaan pelbagai peratusan abu bawahan juga disiasat untuk kajian ini. Simen komposit abu bawahan disediakan dengan kepada nisbah simen dan air yang sama (0.5) di mana penggantian simen ke abu bawahan adalah 10, 20, 30, dan 40 %. Keputusan kekuatan mampatan simen komposit abu bawahan adalah menggalakkan selepas pengawetan dalam air selama 1, 7, 14, 28, 60, 90 dan 360 hari (20.44 hingga 36.79 MPa). Hasil analisis mekanikal menunjukkan bahawa sampel yang mengandungi abu bawahan boleh mencapai kekuatan mampatan yang sangat dekat dengan prestasi yang diperolehi dari simen Portland yang digunakan dalam aplikasi pembinaan. Tambahan pula, gabungan abu bawahan yang paling sesuai ialah penggantian 10%. Penggantian abu bawahan tidak menjejaskan sifat kekuatan kerana masih kekal dalam had ASTM C270. Hasil indeks pozzolanic aktiviti (63 μm dengan penggantian BA 10%) menunjukkan prestasi cemerlang yang hampir sama dengan 0.94 pada hari ke-28 dan mencapai 0.96 pada hari ke 90 yang menunjukkan bahawa abu bawahan adalah bahan pozzolanic dengan pozzolanic aktiviti yang tinggi. Ciri-ciri bahan seperti morfologi, mineralogi, sebatian kimia, dan ternary fasa dieksplorasi dapat memberikan keterangan yang kuat dan penjelasan asas untuk penyelidikan ini. Nisbah penggantian optimum abu bawahan (63 μm dengan penggantian BA 10%) digunakan untuk menentukan penggunaannya dalam rintangan asid dan kebakaran. Faktor utama yang menyebabkan serangan kimia dan fizikal adalah mekanisme pengangkutan kimia dan suhu. Penilaian rintangan asid dan kebakaran simen komposit abu bawahan adalah sama pentingnya dengan ujian mekanikal di mana asid hidroklorik dan sifat-sifat haba boleh diperiksa dengan menjalankan ujian makmal. Hasil rintangan asid menunjukkan bahawa simen komposit abu bawahan mempunyai rintangan yang lebih baik terhadap asid hidroklorik dibandingkan dengan simen Portland. Prestasi rintangan kebakaran simen komposit abu bawahan di bawah 600 ° C mempunyai hasil hampir sama seperti kawalan simen Portland manakala hasil 1200 ° C menunjukkan pengurangan kekuatan mampatan. Penggunaan abu bawahan dengan produktif adalah cara yang terbaik untuk menyelesaikan masalah yang berkaitan dengan pelupusan dan menyelesaikan masalah tanah yang terhad.

BOTTOM ASH EFFECT IN PORTLAND CEMENT COMPOSITE PERFORMANCE

ABSTRACT

The main goal of this study was to investigate the effectiveness of bottom ash in Portland cement in improving the cement properties. The insufficient of published literature regarding to replacement of bottom ash into Portland cement create meticulous investigations in order to use widely through technically viable for highly performance of cement in construction industry. Three types of particle sizes (63, 75, 150 μm) and effect of using various weight percentage of bottom ash were investigated. The bottom ash cement composite were prepared with the same water to cement ratio (0.5) where the replacement of cement to bottom ash was 10, 20, 30, and 40 wt%. The compressive strength result of bottom ash cement composite was encouraging after 1, 7, 14, 28, 60, 90, and 360 days of curing (20.44 to 36.79 MPa). The mechanical analysis result shows that samples containing bottom ash may achieve the compressive strength that are very close to the performance presented by Portland cement. Furthermore, it was observed that the greatest combination of bottom ash was 10 % replacement. The replacement of bottom ash does not affect the strength properties as the strength still remains within the ASTM C270 limit. The optimum pozzolanic activity index result (63 μm with 10 % BA replacement) shows excellent performance that close to 0.94 on the 28th day and reaching 0.96 at 90th day which indicated that bottom ash is a pozzolanic material with high pozzolanic activity. Material properties such as morphology, mineralogical, chemical compound, and ternary phase diagram are explored which provide strong evidence and fundamental explanation to this research findings. The optimum replacement ratio of bottom ash (63 μm with 10 % BA replacement) was used to determine its application in acid and fire resistance. The major factors that causing chemical and physical attack are mechanism of chemical transport and temperature. Evaluation of acid and fire resistance of bottom ash cement composite was as important as mechanical testing where external hydrochloric acid and thermal fire properties were examined by performing the laboratory test. The results of acid resistance indicated that bottom ash cement composite have better resistance towards hydrochloric acid as compared to Portland cement. The performance of fire resistance of bottom ash cement composite under 600 °C have almost identical result as control Portland cement whereas result of 1200 °C shows reduction in compressive strength. The productive use of bottom ash is the best way to solve the problems associated with its disposal by solving landfill problem.

CHAPTER 1 : INTRODUCTION

1.1 Research Background

Portland cement is the material that most important and essential manufactured material that contains major chemical active ingredient in concrete and produced around 4 billion tonnes per year for construction purpose worldwide (Gartner et al., 2017). The popularity of ordinary Portland cement as construction material in construction industry field has been increased due to growth and continuous progress of economies (Zhao et al., 2016). However, production of Portland cement generated large emission of global greenhouse gas carbon dioxide (CO_2) to the atmosphere that approximately 5-7 % and contributed a threat to global warming (Simbolott & Tosato, 2010; Hamidi et al., 2013).

There also appeared some concerns pertaining to the sustainable use of natural resources and the effects of improper waste disposal that become environmental threat (Paris et al., 2016; Kannan et al., 2017). In this situation, there is growing interest on beneficial use of alternative materials with pozzolanic activity for comparable physical and mechanical properties to Portland cement in order to produce value added products from a technical and economical point of view for the profitability of the recycling process (Angulo-Ramirez et al., 2017). The driving force of using the alternatives and renewable material for Portland cement is increasing due to the global awareness towards the environmental issues (Garcia & Sousa-Coutinho, 2013).

Coal is the primary sources of energy that contributed to the generation of electricity worldwide which approximately 36 % of the world electricity production

(Ehsan et al., 2014; Araujo et al., 2016). This rate is likely to remain and last over the next 30 years. According to the World Coal Association, there are around 7.6 billion tons of coal used worldwide (Tiwari et al., 2014). Coal also plays an important role for centuries as it is the faster growing energy source that faster than gas, oil, nuclear, and renewable energy. The main drawback of the increment of coal utilization leads to a very large amount of ashes, a total 3 million tons/year which consists of fly ashes (65 to 85 %) and bottom ashes (15 to 35 %) which create a significant management problem and poses alarming issue.

Fly ash has been widely used as cement replacement material and effectively for production of structural concrete with desirable strength (Naganathan et al., 2012). However, bottom ash as the replacement material for Portland cement is still a premature statement and hence research towards bottom ash has been carried on to investigate its suitability and implemented waste material as a partial cement replacement construction material. Basically the applications of bottom ash are in cement and concrete industries, aggregates, backfill and embankment materials for highroad construction (James et al., 2012). Utilization of ashes helps to save natural resources and reduce energy demand where recycling of ashes is needed either landfilling or used in construction purposes (Lam et al., 2010; Bajare et al., 2013).

Cement composite is a waste management option that against the release of CO_2, particular toxic and hazardous industrial waste (Zamorani, 1992). Adding filler or admixture into Portland cement can improve the properties of Portland cement, thus it was putting high attention towards the development of cement composite (Chung, 2000). The potential of cement composite to replace OPC was supported by the fact that there

were abundant industrial wastes from industries which are suitable to be used as source material for replacement in cement composite.

In today environmental friendly situation and modern concept of green buildings, attentions on materials used in Portland cement have been increased and research towards possible modifications of Portland cement has also increasing the demands for sustainability in construction sector due to their technical advantages in term of strength and durability. Hence, partial or full replacement of cement is considered a sustainable solution towards decreasing the environmental impact of cement production. This research elaborates the effects of bottom ash as replacement material in Portland cement mortar and also its performance as bottom ash cement composite (BACC) since there is no similar research study about the replacement of bottom ash in Portland cement that based on particle sizes and weight percentage of bottom ash.

1.2 Problem Statement

Portland cement is the most common and widely used in construction field due to its availability of the raw materials over the world and ease of preparing. However, there are also some restrictions of the manufacturing process and the raw materials where about 1.5 tons of raw materials is needed in the production of every ton of Portland cement, and at the same time about one ton of CO_2 is released into environment during the production. Hence, the production of Portland cement is extensively used of resources and energy process. The necessarily of finding new cementitious materials to replace Portland cement is needed for sustainable development and also decrease the consumption of natural resources.

There have been growing trend on using waste materials worldwide. Fly ash has been used in manufacturing of cement and concrete from last century. However, use of coal bottom ash in production of cement or concrete is not common throughout the world. It is therefore necessary to examine the physical and mechanical properties of bottom ash for it possible uses in construction field. The published literature is insufficient to bring bottom ash in practical use. Research towards bottom ash is still scarce but there were many investigations found that bottom ash have the cementitious properties which may increase the strength and long term strength properties than concrete itself.

Bottom ash residue needs proper disposal which is not always an effective or simple process. If bottom ash is dumped into a municipal solid waste landfill, it will creates operation problems and pollution (Li et al., 2016). The possibility of using bottom ash is used as cement replacement material which brings several benefits such as possibility of decreasing the natural resources exploration, adequate disposal to the environment, reduce environment burdens of waste accumulation, and lastly recycle to generate usable material (Anjos dos et al., 2017). Bottom ash has the possibility to achieve satisfactory mechanical performance by enhance the compatibility of Portland cement which also possible to obtain new economic and potential environmental low cost materials with a considerable reduction of cement content.

One important factor hindering the accepted use of bottom ash as a construction material is its variability in physical and chemical properties. Therefore, varying of the properties of bottom ash in engineering application might influence the recycle and reuse of bottom ash. In order to achieve the goal of bottom ash to be reused as replacement

material, ensuring a consistent and uniform production of bottom ash by controlling the plant processes and the material which goes into the process of combustion is needed.

The meticulous investigations of properties of replacement of bottom ash into Portland cement are required before it is widely accepted or used in construction industry. As no much literature been reported that the mechanical and material properties of bottom ash cement composite, it is necessary to investigate this research work to evaluate the properties of bottom ash cement composite. Hence, research is being intensified to produce inexpensive bottom ash cement composite with similar, possibly better with engineering application bases. Converting waste material into reusable materials could reduce the waste volume approximately 90 percent. Hence, bottom ash can used as ingredient and recycle into reusable products.

1.3 Research Aim and Objectives

The basic aim of this research is to evaluate the strength potential of bottom ash when replace into Portland cement, in addition this study is motivated by limited knowledge of bottom ash cement composite. Non uniformity of bottom ash such as particle size and chemical composition are the major concern in this research. Studies on bottom ash cement composite in construction application is a reasonable justification to carry out research in order to improve understanding of bottom ash cement composite.

This research tried to understand the effect of three different particle sizes (63, 75, 150 μm) with four different percentage (10, 20, 30 and 40 wt%) replacement percentage of bottom ash on various curing time of Portland cement. The physical and mechanical

properties such as density, compressive strength, pozzolanic activity, acid resistance, fire resistance, durability, morphology structure, mineralogical analysis, and ternary phase characterization will thoroughly discuss in this study. Processing for specific properties with variable sizes and addressing recyclability issues need to be addressed.

The objectives of this research are:

(i) To determine the optimum compressive strength due to different particle sizes and percentage of bottom ash.

(ii) To analyse the best size and percentage for long term performance in curing time of bottom ash cement composite.

(iii) To evaluate the performance of bottom ash cement composite towards acid and fire resistance application.

1.4 Research Scopes

Scope of this research is to centralize on the investigation of the effect, mechanical behaviour, and performance of bottom ash in Portland cement determine through the density, compressive strength test, pozzolanic activity index, acid resistance, fire resistance, durability. Besides that, materials characteristics also will be evaluated according to the various percentage of bottom ash in Portland cement by morphology, mineralogical, and ternary phase analysis at UniMAP laboratory. For each topic, a literature survey was performed to identify the characteristic of Portland cement and bottom ash cement composite.

A number of samples was prepared in the laboratory to determine the optimum ratio according to the size variation of bottom ash and mechanical behaviour of bottom ash cement composite. There are four series of composite mix design that contain Portland cement with bottom ash and one control mix (pure Portland cement) were casted. Each of the four series divided into three categories sizes (63, 75, 150 µm) of bottom ash. The percentage of bottom ash was 10, 20, 30 and 40 % from the total weight of mortar with Portland cement which the water cement ratio is 0.5.

The hardened cement composite was taken out from the mould after 24 hours after casting and cured in the curing tank with the curing period of 1, 7, 14, 28, 60, and 90 days for all the samples whereas 360 days were used to determine for long curing performance. The weight measurement and compressive strength test was conducted after the curing period while following with materials characterizations. Collection of data for the proper investigation into the strength characteristics of bottom ash composite cement with literatures that collected from books and journals that based on engineering properties of bottom ash composite cement is obtained and discussed in the following chapter. While for the acid resistance, fire resistance, and durability test will be studied and discussed after the tests are completed by determining the optimum mixing ratio and best combination.

1.5 Thesis Outline

This thesis is divided into five chapters. Introduction is a Chapter 1 which provides the general overview of current research efforts, problem statement, aims, and specific objectives of the study for the replacement of waste material bottom ash and

converting it into used material in construction area with possibly better engineering application base. Chapter 2 describes the literature review of Portland cement, bottom ash, its production, properties, and uses. Besides that, it also discusses the literature and recent achievements in studies of bottom ash composite cement that available and published over the period. Chapter 3 discusses about the research methodology with various technical experiments and materials to investigate the characteristics of bottom ash composite cement. While Chapter 4 discusses the experimental results that obtained with the corresponding sizes, percentage and curing period based on density, compressive strength, acid resistance, fire resistance, durability, morphology, chemical compounds, and chemical components of the bottom ash cement composite. Chapter 5 summarizes the conclusions drawn from the results presented in Chapter 4 and provides recommendations for future work.