PERFORMANCE OF CONCRETE BY USING PULVERIZED FUEL ASH (PFA) AS CEMENT REPLACEMENT MATERIAL

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ABSTRACT

Through public concerns and research efforts, the coal combustion by-product materials have potential to be utilized as construction material to replace conventional ordinary Portland cement (OPC). Recycling the coal combustion by-product materials is the act of processing the waste material to creating an alternative product. The used of pulverized fuel ash (PFA) as a pozzolanic material as a partial cement replacement for producing concrete will reduce the environmental pollution problems create by excessive production of cement, as well as the requirement for disposing the ash. Mix design facilitates the percentage used of pulverized fuel ash (PFA) concrete assessed together with the aggregates and cement. In this present investigation, PFA concrete is mix according to 10%, 20% and 30% by weight of cement replaced with PFA. The present study designed to determine the effectiveness of PFA and discovered its potential as a partial cement replacement in concrete. It is also to study the effectiveness of PFA concrete toward compressive strength and durability in term of increasing its resistance toward chemical attacks namely sulphate and acid. The continuation of pozzalanic activity in PFA concrete would reduce the porosity of concrete at 90 days of curing age. The entire PFA concrete specimens prepared consist of PFA-20% as partial cement replacement material indicates the optimum usage of PFA. Conclusively, the introduction of PFA as cement replacement in concrete as an alternative material would improve the properties of PFA concrete.

ABSTRAK

Secara umumnya, perhatian oleh pihak masyarakat dan usaha kajian, bahan keluaran produk pembakaran arang batu mempunyai potensi untuk dimanfaatkan sebagai bahan pembinaan untuk menggantikan simen Portland biasa (OPC). Kitar semula bahan keluaran produk pembakaran arang batu adalah tindakan pemprosesan bahan terbuang untuk digunakan dalam mencipta produk alternatif. Penggunaan Abu Arang Batu (PFA) yang merupakan bahan pozzolana sebagai bahan pengganti separa simen untuk menghasilkan konkrit akan mengurangkan masalah pencemaran alam sekitar oleh pengeluaran karbon dioksida yang berlebihan dalam membuat semen, serta keperluan untuk pembuangan abu. Rekabentuk campuran digunakan untuk menentukan peratusan PFA konkrit yang dicampur bersama-sama dengan agregat dan simen. Dalam penyiasatan ini, PFA akan digunakan ke dalam konkrit mengikut 10%, 20% dan 30% dari berat simen digantikan dengan PFA. Penyelidikan ini direka untuk menentukan keberkesanan PFA dan mendapatkan potensinya sebagai pengganti sebahagian campuran dalam konkrit. Hal ini juga untuk mempelajari keberkesanan konkrit PFA terhadap kekuatan mampatan dan daya tahan konkrit PFA terhadap meningkatkan ketahanan serangan kimia iaitu larutan sulfat dan asid. Kegiatan pozzalanic yang berterusan pada konkrit PFA akan mengurangkan kandungan lompang dalam konkrit pada 90 hari tempoh pemeraman. Keseluruhan spesimen konkrit PFA yang dihasilkan mengandungi PFA-20% sebagai bahan pengganti simen separa menunjukkan penggunaan optimum PFA. Kesimpulannya, pengenalan PFA sebagai pengganti semen dalam konkrit sebagai material alternatif akan memperbaiki konkrit PFA.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Concrete is the most widely consumed material in the world, after water. Nowadays, most of the construction for buildings and infrastructures in Malaysia are using concrete as construction material. It is a construction material composed of cement as well as other cementations materials such as pulverized fuel ash (PFA) and slag cement, aggregate water, and chemical admixtures. Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material. As it gives benefit to the construction field, it's also give environmental problem. The cement industry is one of the primary producers of carbon dioxide (CO_2), cement kiln CO_2 is released from calcinations of limestone (±50%) and from the combustion of fuels (±50%), and cement production accounts for approximately 5% of the global CO_2 emissions (Guimares & Pade, 2006).

According to Environment Institute Association (2006) noted that more than 60% of the CO_2 emissions from industrial sources originate from cement manufacturing. Four basic materials are required to make cement: namely calcium, silicon, aluminum, and iron. Substrates of these materials are ground into a powder and heated in a kiln. While in the kiln, limestone (the predominant source of calcium) is broken down into carbon dioxide and lime. The carbon dioxide is driven off into the atmosphere. The production of the cement is necessary to keep the development of a country, but the environmental problems also should be taken into consideration. The alternative way to let the engineering field giving its benefit for the good of all mankind is to reduce the excessive use of cement in one construction.

The proper mixes and proportion of cement may be important to obtained the standard quality of concrete, the engineer have to come out a concrete with less used of cement in mixes and replace it with another material without having the decrease of the concrete quality. Gutt and Smith (1975) stated that waste materials can make a small but useful contribution to supplies of aggregates and cement. The potential for greater use of specific wastes is examined. Attention is focused on problems of specification and acceptance of waste materials, products derived from wastes, and from other unused materials. In view of problems in excessive cement used which polluting nature, the waste material can be used to replace a small proportion of cement to reduce the rate of environmental problem.

However there are not many waste materials suitable to replace the proportion. The study by Hughes and Al-Ani (1991) stated that mix design facilitates the economical use of available materials to provide a concrete with certain a desirable characteristics. Mix design for PFA concrete should therefore be no exception. The relevant properties of economically available PFAs should be assessed together with those for the aggregates and cement and a suitable concrete designed for the required criteria for quality (e.g. strength) and for workability (e.g. Vebe time). The study shows that the PFA can be taken as consideration to used in the construction material as its benefit to the environment which controlling the produce of wastage that increase by year and preserving the air purity by pollution through the emission of carbon dioxide into the air by the process of making cement in industrial. It is said that the design of modified concrete can solve environmental problems.

According to American Coal Ash Association (2003) stated that PFA is the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. It is produced by coal-fired electric and steam generating plants. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed PFA, remain suspended in the flue gas. Prior to exhausting the flue gas, PFA is removed by particulate emission control devices, such as electrostatic precipitators or filter fabric bag houses.

Furthermore, with PFA utilization, especially in concrete, has significant environmental benefits including: (i) increasing the life of concrete roads and structures by improving concrete durability, (ii) net reduction in energy use and greenhouse gas and other adverse air emissions when fly ash is used to replace or displace manufactured cement, (iii) reduction in amount of coal combustion products that must be disposed in landfills, and (iv) conservation of other natural resources and materials (American Coal Ash Association, 2003).

The design of modified concrete combining PFA is a concern for the preservation of the environment and the conservation of natural resources, the composition of PFA is as similar to silica fume but with more finer compared to the PFA. Silica fume is a pozzolanic material which results in higher reactivity than for PFA but with a downturn in workability test. In order to derive the maximum short term and long term benefits from the use of these materials in high performance concrete, ternary blends exploiting the potential synergy between these materials may be necessary (Khan et al., 2000).

Concrete is used as a construction material in hostile environments in structures such as seafloor tunnels, offshore piers and platforms, highway bridges, sewage pipes, and containment structures for solid and liquid wastes containing toxic chemicals and radioactive elements. Numerous publications reporting improved rheology and cohesiveness, lower heat of hydration, lower permeability and higher resistance to chemical attack resulting from the use of different mineral admixtures have emerged over the years. The requirements for acceptable durability performance in such conditions go beyond those achievable with ordinary cements. As a result, the blending of ordinary Portland cement (OPC) with pozzolanic materials has become an increasingly accepted practice in such structures. The used of pozzolanic material like PFA also can improve the quality of concrete through its composition of chemical (Khan et al., 2000).

In PFA replaced cement, the $Ca(OH)_2$ content reduction is due to the secondary hydration reaction. During hydration, in PFA concretes lime is consumed but in OPC concrete lime is produced. This is the main advantage of using PFA cements to decrease the permeability of the concrete and thereby increasing the corrosion resistance properties. The main hydrated phases produced during the pozzolanic reaction at ambient temperature are CSH, C_2ASH and C_4AH. Different factors can influence the reaction kinetics and the amounts of the phases produced, but the hydration time is the most important factor. Variation of calcium hydrates content with hydration time is important factor for pore filling characteristics. In PFA concretes in presence of water, PFA can react with $Ca(OH)_2$ to form secondary calcium hydrates (both aluminate hydrate and silicate hydrate). This secondary calcium hydrate fills the large capillary voids and this process of transformation is referred to as the so-called pore size refinement. It's resulting to self healing by just curing the modified concrete into suitable condition which a hairline crack can be easily auto-fixed (Saraswathy & Song, 2007).

1.2 Problem Statement

More than 50% of the carbon dioxide (CO_2) emitted during cement production originates from the calcinations of limestone. This CO_2 is reabsorbed during the life cycle of cement based product such as concrete and mortars in a process called carbonation. The impact that concrete carbonation has in the assessment of CO_2 emissions from cement production has not been fully documented. Specifically, there is a lack of knowledge about the carbonation of demolished and crushed concrete. The existing methods for calculating carbonation do not take into account the consequences after the concrete has been demolished. Moreover, the contribution of the cement and concrete industry to net CO_2 emissions may be significantly overestimated.

Some industrial by products and waste materials are available in large quantities and with technically proper method to handling and economically feasible outlets could be found, it might contribute to solving some of the aggregate supply problems and to the conservation of natural resources and reduce the dereliction which might otherwise be caused by the extraction of the natural materials. The method, however, important constraints on the use of waste materials; it must fulfill the engineering requirements in terms of physical properties and they must not contain excessive amounts of deleterious components which might cause problems in use.

1.3 Objective of Study

The objectives of the study are:

i) To determine the effectiveness of pulverized fuel ash (PFA) and discovered its potential as a partial replacement mixes in concrete.

ii) To determine the effect of pulverized fuel ash (PFA) towards mechanical properties of concrete.

iii) To determine the effect of pulverized fuel ash (PFA) towards performance and durability of concrete.

1.4 Scope of Study

This study concentrated on investigation of compressive strength and durability of pulverized fuel ash (PFA) concrete and plain concrete as a control mix. Each series of concrete were designed for grade 30 with constant water cement ratio (w/c) of 0.5 was conducted. The plain concrete compose of cement, water, aggregate and sand were considered as a control mix without replacing with PFA (PFA-0%). Three series of concrete mix design with PFA as cement replacement were composed as an unconventional mixes comprises of 10%, 20% and 30% from the total weight of ordinary Portland cement. The PFA concretes were labeled as PFA-10%, PFA-20% and PFA-30% respectively.

The concrete were cast and poured into mould and the hardened concrete was taken out from the mould after 24 hours. Then, the hardened concrete was cured in water for 7, 28, 60 and 90 days for all mixes. The compressive strength tests were conducted after the specimens matured due to curing period for entire specimens. The testing are followed as accordance to BS1881: Part 119: 1983.

On the other hand, the durability tests consist of acid test, sulphate test and porosity test also were considered. For acid test, all the specimens were submerged into the sulfuric acid (H_2SO_4). The test was carried out to determine the percentage of weight losses. Meanwhile, the percentage of shrinkage (strain deformation) were tested subjected to sulphate test namely magnesium sulfate solution ($MgSO_4$). All the durability tests were conducted along three (3) months submerging into the solutions.

In addition, the entire specimens also were tested on the porosity test in order to determine percentage of porous content. The test was conducted after all the specimens cured in water and matured at 90 days of curing. Vacuum saturation is one best method to be used as accordance to ASTM C 642, 2002.

1.5 Significant of Study

An environmental issue is a problem that many countries had taken it seriously; they are already having the technology to reduce the pollution. In Malaysia, the way in handling the pollution still lame, concern for the preservation of the environment and the conservation of natural resources has focused attention on the means of fulfilling the future demand for cement. Some industrial byproducts and waste materials are available in large quantities and, if technically sound and economically feasible outlets could be found, the study might contribute to solving some of the cement supply problems and to the conservation of natural resources and reduce the pollution.

The prospects for future use of waste materials in concrete include the potential for greater use of pulverized fuel ash (PFA) and granulated slag as cementitious materials, and increased production of synthetic aggregates. The potential for greater use of PFA probably lies in its greater use to produce partial material in cement to meet a possible demand arising from the new higher insulation standards required in domestic housing, perhaps in expanded production of sintered aggregates, and possibly most importantly in wider use as a pozzolanic material either directly at the concrete batching plant or in the production of Portland pozzolanic cements. Some of the environmental and economic advantages to be gained by wider use of PFA, as a pozzolan recently have been considered.

Owing to its pozzolanic properties, PFA is used as a replacement for some of the Portland cement content of concrete. The replacement of Portland cement with PFA is considered by its promoters to reduce the greenhouse gas "footprint" of concrete, as the production of one tonne of Portland cement produces approximately one tonne of CO_2 as compared to zero CO_2 being produced using existing PFA. New PFA production, the burning of coal, produces approximately 20 to 30 tonnes of CO_2 per tonne of PFA. Since the worldwide production of Portland cement is expected to reach nearly two billion tonne by 2010, replacement of any large portion of this cement by PFA could significantly reduce carbon emissions associated with construction, as long as the comparison takes the production of PFA as a given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete is a common material that has been used as structural which hardened building material created by combining a chemically inert mineral aggregate (usually sand, gravel, or crushed stone), a binder (natural or synthetic cement), chemical additives, and water. Another factor that concrete has been choosing as the construction material is it can be shape to any shape desired. As concrete dries, it acquires a stone-like consistency that renders it ideal for constructing roads, bridges, water supply and sewage systems, factories, airports, railroads, waterways, mass transit systems, and other structures. Concrete has a high compressive strength compared to tensile strength, low thermal and electric conductivity and low toxic. As its good to its benefit, it's also giving the bad effect due to environment and high cost toward its increased used by year. Substituting a partial percentage of cement used in concrete with pulverized fuel ash (PFA), its can reduce the environmental problem, making good of unrecyclable wastage furthermore to gain an improved concrete product with less cost.

However the method and design of getting the waste material to specifically meet the good proportion of PFA concrete still in research. PFA is one of much wastage which as be claim as the prospect for the future use of waste material in concrete. Studied by Gutt and Smith (1975) reveal that, the technical evaluation of waste materials is, therefore, the essential first stage towards utilization but this in itself is not sufficient since the criteria which govern utilization are ultimately economic. Proper economic analysis should take into account social and environmental costs and benefits. Attention should be given to these non-technical factors in evaluating the prospects of application of a particular process and in making a choice in the allocation of limited resources for research or development.

Furthermore, Gutt and Smith (1975) also has described that the present utilization of the major byproducts as aggregates and as cements concerned primarily with some problems in specification and acceptance of waste materials and with the potential for their future use as aggregates in concrete. The research also noted that use of waste materials in concrete include the potential for greater use of PFA and granulated slag as cementitious materials, and increased production of synthetic aggregates. PFA may find greater use in the production of aerated concrete and sintered lightweight aggregates but the major use worth developing is as a pozzolanic material either to produce blended Portland/PFA cements or in direct use at the concrete mixer. The pozzolanic characteristic in PFA can give an improvement and costly concrete to become a practiced in concrete research and development, the proper design and proportion partial replacement should be comes up to meet the expectation by potential of PFA.

2.2 Pulverized Fuel Ash (PFA)

Survey by Gutt and Smith (1975) was found that pulverized fuel ash (PFA) is one the waste material that identified as solid waste which stockpile each year and potentially usable material in concrete product. PFA is one of the residues generated in the combustion of coal. PFA is generally captured from the chimneys of coal-fired power plants, and is one of two types of ash that jointly are known as coal ash; the other, bottom ash, is removed from the bottom of coal furnaces. Depending upon the source and makeup of the coal being burned, the components of PFA vary considerably. The potential for greater use of PFA in concrete consequently resolve some of the environmental and economic advantages, and as a pozzolan to improve the properties of concrete itself.

Owing to its pozzolanic properties, PFA is used as a replacement for some of the Portland cement content of concrete. The use of PFA as a pozzolanic ingredient was recognized and it is use as a partial replacement for Portland cement. It can replace up to 30% by mass of Portland cement, and can add to the concrete's final strength and increase its chemical resistance and durability. Due to the spherical shape of PFA particles, it can also increase workability of cement while reducing water demand (American Coal Ash Association, 2003).

Generally only those PFA particles which float on water, which are only around 1% of the total, are considered to be cenospheres. Since the relative densities of the constituent materials of PFA particles are significantly greater than 1 the flotation of these cenospheres must be due to buoyancy imparted by contained gases. The measurement of overall actual relative density requires PFA to be crushed, which can be difficult because of the glassy, spherical particulate nature of the material. However, "Fillite", commercially available PFA floaters, proved amenable to milling and an absolute relative density of 2.66 was determined. Thus, if PFA particles do not contain gas to impart buoyancy they would sink in water (Dhir et al., 1987).

2.2.1 Characteristic of Pulverized Fuel Ash (PFA)

Research conduct by American Coal Ash Association (2006), the characteristic of pulverized fuel ash (PFA) as listed as below:

(i) **Size and Shape**

PFA is typically finer than Portland cement and lime. PFA consists of silt-sized particles which are generally spherical, typically ranging in size between 10 and 100 micron. These small glass spheres improve the fluidity and workability of fresh concrete. Fineness is one of the important properties contributing to the pozzolanic reactivity of PFA.

(ii) **Color**

PFA can be tan to dark gray, depending on its chemical and mineral constituents. Tan and light colors are typically associated with high lime content. A brownish color is typically associated with the iron content. A dark gray to black color is typically attributed to elevated unburned carbon content. PFA color is usually very consistent for each power plant and coal source.

(iii) **Chemistry**

PFA consists primarily of oxides of silicon, aluminum iron and calcium. Magnesium, potassium, sodium, titanium, and sulfur are also present to a lesser degree.

When used as a mineral admixture in concrete, PFA is classified as either Class C or Class F ash based on its chemical composition. American Association of State Highway Transportation Officials (AASHTO) M 295 [American Society for Testing and Materials (ASTM) Specification C 618; 2003] defines the chemical composition of Class C and Class F PFA.

Class C PFA are generally derived from sub-bituminous coals and consist primarily of calcium alumino-sulfate glass, as well as quartz, tricalcium aluminate, and free lime (CaO). Class C PFA is also referred to as high calcium PFA because it typically contains more than 20% CaO. Class F PFA are typically derived from bituminous and anthracite coals and consist primarily of an alumino-silicate glass, with quartz, mullite, and magnetite also present. Class F, or low calcium PFA has less than 10% CaO. Table 2.1 shows the compounds content of PFA class C, PFA class F and ordinary Portland cement.

Table 2.1: Sample Oxide Analyses of PFA and Portland Cement

Compounds	Compound Content		
	PFA class F	PFA class C	Portland Cement
SiO_2	55	40	23
Al_2O_3	26	17	4
Fe_2O_3	7	6	2
CaO	9	24	64
MgO	2	5	2
SO_3	1	3	2

2.2.2 Quality of Pulverized Fuel Ash (PFA)

Quality requirements for pulverized fuel ash (PFA) vary depending on the intended use. PFA quality is affected by fuel characteristics (coal), co-firing of fuels (bituminous and sub-bituminous coals), and various aspects of the combustion and flue gas cleaning/collection processes. The four most relevant characteristics of PFA for use in concrete are loss on ignition (LOI), fineness, chemical composition and uniformity.

(i) **Loss of Ignition**

Loss of Ignition (LOI) is a measurement of unburned carbon (coal) remaining in the ash and is a critical characteristic of pulverized (PFA), especially for concrete applications. High carbon levels, the type of carbon (i.e., activated), the interaction of soluble ions in PFA, and the variability of carbon content can result in significant air entrainment problems in fresh concrete and can adversely affect the durability of concrete. AASHTO and ASTM specify limits for LOI.

(ii) **Fineness**

Fineness of PFA is most closely related to the operating condition of the coal crushers and the grind ability of the coal itself. For PFA use in concrete applications, fineness is defined as the percent by weight of the material retained on the 0.044 mm (No. 325) sieve. A coarser gradation can result in a less reactive ash and could contain higher carbon contents. Limits on fineness are addressed by ASTM. PFA can be processed by screening or air classification to improve its fineness and reactivity

(iii) **Chemical composition**

Chemical composition of PFA relates directly to the mineral chemistry of the parent coal and any additional fuels or additives used in the combustion or post-combustion processes. The pollution control technology that is used can also affects the chemical composition of the PFA. Electric generating stations burn large volumes of coal from multiple sources. Coals may be blended to maximize generation efficiency or to improve the station environmental performance. The chemistry of the PFA is constantly tested and evaluated for specific use applications. Some stations selectively burn specific coals or modify their additives formulation to avoid degrading the ash quality or to impart desired PFA chemistry and characteristics.

(iv) **Uniformity**

Uniformity of PFA characteristics from shipment to shipment is imperative in order to supply a consistent product. PFA chemistry and characteristics are typically known in advance so concrete mixes are designed and tested for performance.

The quality of the PFA is no doubt an important factor to be considerate into this study. Table 2.2 shows the guidance documents which be used for PFA quality assurance as been implement in this study.

Table 2.2: Guidance Documents Used for PFA Quality Assurance

Standard	Content
ACT 229R	Controlled Low Strength Material (CLSM)
ASTM C 311	Sampling and testing Fly Ash/PFA or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete.
AASHTO M 295 ASTM C618	Fly Ash/PFA and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
ASTM C593	Fly Ash/PFA and Others Pozzolans for Use With Lime

2.3 Pulverized Fuel Ash (PFA) Concrete

The use of pulverized fuel ash (PFA) in Portland cement concrete (PCC) has many benefits and improves concrete performance in both the fresh and hardened state. PFA use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. PFA use is also cost effective. When PFA is added to concrete, the amount of Portland cement may be reduced. PFA also is used in concrete admixtures to enhance the performance of concrete. Portland cement contains about 65% lime. Some of this lime becomes free and available during the hydration process. When PFA is present with free lime, it reacts chemically to form additional cementitious materials, improving many of the properties of the concrete.