PERFORMANCE OF CONCRETE BY USING PALM OIL FUEL ASH (POFA) AS A CEMENT REPLACEMENT MATERIAL

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ABSTRACT

Malaysia as the world's largest exporter of palm oil has been facing problem in disposing palm oil fuel ash, a by-product of palm oil mill since many years ago. Through public concerns and research efforts, the agrowaste by-product materials have potential to be utilized as construction material to replace conventional ordinary Portland cement (OPC). In this study, the effectiveness of agrowaste ash by-product namely palm oil fuel ash (POFA) was developed as an alternative materials to replace the OPC. POFA cement-based concrete is a concrete produced by integrating POFA as a pozzolan in concrete. The quality of POFA was improved by grinding until the median particle sizes were 50 microns. The unground and ground POFA were used to replace OPC by 0%, 10%, 20% and 30% by weight of cement binder. The compressive strength of POFA-concretes due to 7, 28, 60 and 90 days of curing ages were investigated. In addition, the durability resistance of POFA-concretes toward sulphate and acid solution also were assessed. The results revealed that the compressive strength of POFA-concretes was much lower than that of concrete without POFA. Conversely, the replacement of Portland cement by 20% of POFA recorded highest in strength compare to those POFA-concretes at 90 days. In case durability test, after being immersed in suphate solution for 90 days, the POFA-concretes with 30% of POFA had reduce expansion level compare to both of mixture. It is revealed that ground POFA is an excellent pozzolanic material and can be used as an alternative cement replacement in concrete. It is recommended that the optimum replacement levels of OPC by POFA are 30% and 20% mixture for a good strength in compressive test.

ABSTRAK

Malaysia merupakan pengeluar kelapa sawit terbesar didunia menghadapi masalah dalam pembuangan debu kelapa sawit, penghasilan daripada kelapa sawit sejak beberapa tahun yang lalu. Melalui kesedaran orang ramai dan juga usaha ujikaji, pembuangan sisa ini ada potensi untuk digunakan dalam bahan pembinaan bagi menggantikan simen yang kebiasaannya digunakan iaitu simen Portland (OPC). Dalam kajian ini, keberkesanan pengeluaran bahan buangan kelapa sawit yang dinamakan debu kepala sawit (POFA) dibangunkan sebagai bahan alternatif untuk menggantikan OPC. Simen berasaskan POFA konkrit dikeluarkan oleh campuran POFA sebagai pozolana dalam konkrit. Kualiti POFA akan meningkat apabila kisaran dilakukan sehingga kehalusan tahap sederhana iaitu pada saiz 50 mickron. Pofa yang telah dihaluskan akan digunakan untuk menggantikan OPC sebanyak 0%, 10%, 20% dan 30% mengikut peratus berat OPC.Kekuatan mampatan konkrit POFA akan diuji selepas mengalami proses pengawetan sehingga umur konkrit 7, 28, 60 dan 90 hari. Tambahan pula, ketahanlasakan oleh konkrit POFA terhadap serangan sulfat dan juga acid turut dikaji. Keputusan menunjukkan bahawa kekuatan mampatan konkrit POFA lebih rendah berbanding dengan konkrit biasa. Sebaliknya, penggantian simen oleh 20% POFA menunjukkan rekod tertinggi dalam kekuatan mampatan berbanding dengan bancuhan POFA yang lain pada umur 90 hari. Dalam ujikaji ketahanlasakan pula, selepas konkrit direndam didalam larutan sulfat selama 90 hari, konkrit POFA dengan bancuhan 30% POFA mengalami keturunan tahap pengembangan berbanding dengan kedua-dua bancuhan. Kehalusan POFA merupakan bahan pozolana yang terbaik dan boleh digunakan sebagai bahan alternatif penggantian simen. POFA 20% dan 30% dicadangkan sebagai peringkat menggantikan simen bagi mendapat keputusan kekuatan mampatan yang tinggi dalam ujikaji.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is a very important material and widely used in construction material since an ancient time. Concrete is no doubt is important building material, playing a part in all building structure. It is must environmental friendly construction materials with offer the stability and flexibility in designing all building structures. Concrete are attractive for use as construction materials. Since, there are many advantages of concrete such as built-in-fire resistance, high compressive strength and low maintenance. However, concrete also have a disadvantage which is the concrete are inherently brittle material.

On the other hand, concrete is also well known of its major problem associated with low tensile strength compared to compressive strength. Because of that, many new technologies of concrete and some modern concrete specifications approach were introduced. There have been many experimental works was conducted by introducing a new material or recycled material as a replacement to aggregate or cement in concrete.

Nowadays, the use of recycled materials as concrete ingredients is gaining popularity and development because of increasingly stringent environmental legislation. Furthermore, there is significant research on many different materials for cement usage substitutes and replacement such palm oil fuel ash (POFA), pulverize fuel ash (PFA) and many others fiber and pozzolanic material. Since Malaysia is second largest producer in palm oil industry, the wastage of the palm oil can be used to replace in small amount of cement.

Palm oil industry is one of the most important agro industries in Malaysia. Besides the production of crude palm oil, a large amount of solid waste is also an output from the palm oil industry. Annually, more than two million tones of solid waste of palm oil residue, such as palm fiber, shells, and empty fruit bunches are produced (Office of the Agricultural Economics, 2002). Utilization of palm oil fuel ash (POFA) is minimal and unmanageable, while its quantity increases annually and most of the POFA are disposed of as waste in landfills causing environmental and other problems. On the other, many researchers have been studied on the use of agro waste ashes as constituents in concrete, namely rice-husk ash (Mehta, 1977) sawdust ash (Udoeyo & Dashibil, 2002) and bagasse ash (Singh et al., 2000). The results revealed that these agro waste ashes contained a high amount of silica in amorphous form and could be used as a pozzolanic material. According to ASTM C 618 (2001) defines pozzolanic material as a material that contains siliceous or siliceous and aluminous material by composition.

In general, a pozzolanic material has little or no cementing properties. However, when it has a fine particle size, in the presence of moisture it can react with calcium hydroxide at ordinary temperatures to provide the cementing property. POFA is one of the agro waste ashes whose chemical composition contains a large amount of silica and has high potential to be used as a cement replacement (Tangchirapat et al., 2003).

According to Abu (1990) the pioneer in POFA research has embarked on studying agricultural ash in Malaysia and finally acknowledged that POFA is a pozzolanic material and able to be replace as partial cement replacement up to 35% in mortar mix that could exhibit similar strength as control mortar. Then studies have been continued by (Awal & Hussin, 1996) that highlighted that POFA concrete gain maximum strength when 30% of the cement was replaced with POFA. It is reported that the maximum strength gain occurred at the replacement level of 30% but further increase in the ash content would reduce the strength of concrete gradually (Awal & Hussin, 1996). However, the result of POFA performance once added in aerated concrete still yet to be studied. Besides that, added that increasing in fineness of POFA would lead to greater concrete strength development than the coarser one. It also has been found that POFA could produce a more durable concrete. POFA possess good characteristic towards chemical attack especially sulphate and acid and also other chemical agent when it is used as partial cement replacement in concrete mix (Awal, 1998). As an additional benefit Awal & Hussin (1997) also stated that incorporation of POFA as partial cement replacement in concrete result in significant increase in chemical resistance to acidic environment. Moreover, despite the higher alkali content POFA, it has been effective in suppressing expression due alkali-silica reaction. However, performance of POFA when incorporated as partial cement replacement in concrete still remains undiscovered.

Most of the concrete produced today are a multi component product containing one or more admixtures in addition to the four basic component which is cement, water, fine aggregate and coarse aggregate. For every component, one usually has several choices that could influences the cost of the end product and its behavior in service. Among the constituent components, however, cement or cementitious materials as a whole play a vital role in producing strong and durable concrete. For many purposes a pozzolan has been regarded as a substitute for a proportion of cement in a concrete

1.2 Problem Statement

Generally, the wastage of palm oil from the palm oil from the palm oil industry was increasing eventually. It is become a major problem to palm oil power plants because this wastage from palm oil are not reused and recycle in any works. To utilize this waste material as a active pozzolanic admixtures. These pozzolanic admixtures are used for reducing the Portland cement content in mortar and concrete production. The positive effects exerted by such pozzolanic admixtures on properties of Portland cement mortar and concrete have been emphasized in many studies. In addition to a strength gain, it was shown that such admixtures could improve the sulfate resistance of the Portland cement mortar and concrete However, what can be expected in a specific situation will depend on the mineralogical and chemical composition of the mineral admixture.

1.3 Objective of Study

The objectives of the study are:

a) To study the effectiveness of palm oil fuel ash (POFA) and discovered its potential as a partial replacement mixes in concrete.
b) To study the effect of palm oil fuel ash (POFA) towards mechanical properties of concrete.
c) To study the effect of palm oil fuel ash (POFA)) towards performance and durability of concrete.

1.4 Scope of Study

This study concentrated on investigation of compressive strength and durability of palm oil fuel ash (POFA) 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 POFA (POFA-0%). Three series of concrete mix design with POFA as cement replacement were composed as an unconventional mixes comprises of 10%, 20% and 30% from the total weight of ordinary Portland cement. The POFA concretes were labeled as POFA-10%, POFA-20% and POFA-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 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

Concrete plays an important role in the beneficial use of these materials in construction. Many modification and developments have been made to place industrial waste such as concrete itself and waste material like POFA as a cement replacement. This research is to investigate and propose another way as an alternative to revealed that the replacement of POFA in Portland cement increased setting time of paste

One of the main goals of sustainable waste management is to maximize recycling and reuse. Recycling is a logical option for materials not suitable for composting. With increasing environmental pressure to reduce waste and pollution and to recycle as much as possible, the concrete industry has begun adopting a number of methods to achieve these goals.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete is a man-made material, is the most widely used building material in the construction industry. It consists of a rationally chosen mixture of binding material such as cement, well graded fine and coarse aggregates and water. Concrete has a high compressive strength, built-in-fire resistance, durability, and low maintenance. However, concrete is an inherently brittle materials with a relatively low tensile strength as compared to its compressive strength, requiring a lot of reinforcement.

According to Ahmad et al., (2008) one of the potential recycles material from palm oil industry is palm oil fuel ash which contains siliceous compositions and reacted as pozzolans to produce a stronger and denser concrete. There are many experimental works conducted by introducing recycled material likes palm oil fuel ash (POFA) as a replacement of the cement with different percentages to improve the properties of concrete.

As Malaysia focusing into main hub for bio-technology industry in the region, it is estimated that million tones of its waste will be produced yearly and Malaysian Government acquired to allocate more dumped area for disposal. Through public concerns and research efforts, the waste materials have potential to be utilized as construction material to replace conventional Ordinary Portland cement (OPC) (Ahmad et al., 2008).

2.2 Origin of POFA

Palm oil fuel ash is a by-product produced in palm oil mill. After palm oil is extracted from the palm oil fruit, both palm oil husk and palm oil shell are burned as fuel in the boiler of palm oil mill. Generally, after combustion about 5% palm oil fuel ash by weight of solid wastes is produced (Sata et al., 2004). The ash produced sometimes varies in tone of colour from whitish grey to darker shade based on the carbon content in it. In other words, the physical characteristic of POFA is very much influenced by the operating system in palm oil factory.

In practice, POFA produced in Malaysian palm oil mill is dumped as waste without any profitable return (Sumadi & Hussin, 1995). Either in 20th or 21st century, POFA is still considered as a nuisance to the environment and disposed without being put for any other use as compared to other type of palm oil by-product. Since Malaysia is continuous to increase production of palm oil, therefore more ashes will be produced and failure to find any solution in making use of this by-product will create severe environmental problems.

2.3 POFA a New Pozzolanic Material

Malaysia is the world's leading producer and exporter of palm oil and palm oil products with a reputation for quality and consistency. To date, there are more than two hundred palm oil mill plants operating in the country that are self sufficient industry as far as energy utilization is concerned. On average, 43 tonnes or more empty fruit bunches, fibres and shells are generated per 100 tonnes of fresh fruit bunches processed. It has been approximated that the total solid waste generated by this industry has amounted to more than 8 million tons a year (Rashid & Rozainee, 1993). The palm fibre and shell obtained as waste products by the industry are generally used as boiler fuel to produce steam for electricity generation and palm extraction process. The ash produced by burning palm fiber and shell is considered to be a waste product, the disposal of which causes lot of problems. As a normal practice this ash is dumped into wastelands behind the mill. Experimental laboratory studies, however, have shown that this ash has good pozzolanic properties that make possible the replacement of cement in mortar and cement mixes. Although identified with various name namely palm oil fly ash (Samsuri & Subbiah, 1997) and oil-palm ash (Tay, 1990).

2.4 Chemical Composition of POFA

Both physical properties and chemical analysis indicated that POFA is a pozzolanic material (Sumadi & Hussin, 1993). This pozzolanic material can be grouped to Class C and Class F as specified in (ASTMC618-92a, 1994). POFA is moderately rich in silica content meanwhile lime content is very low as compared to OPC

(Awal & Hussin, 1997). However, the chemical composition of POFA can be varied due to operating system in palm oil mill.

2.5 Strength and Durability of POFA

20th century has been a meaningful one for researchers from Faculty of Civil Engineering of Universiti Teknologi Malaysia when they successfully discovered that the palm oil fuel ash that been considered worthless can actually be made used in construction industry specifically in concrete technology. Starting from the time onwards until this century the POFA use in concrete production continued to be studied and revealed by researchers in Asian region especially. Until now, some researchers Sata et al., (2004)) that has been diligently studying on POFA use has able to successfully reveal the benefits of POFA in concrete technology in terms enhancement towards the properties of concrete either strength or durability aspect.

Abu (1990) the pioneer in POFA research has embarked on studying agricultural ash in Malaysia and finally acknowledged that POFA is a pozzolanic material and able to be replace as partial cement replacement up to 35% in mortar mix that could exhibit similar strength as control mortar. Then studies have been continued by Awal & Hussin, (1996) that highlighted that POFA concrete gain maximum strength when 30% of the cement was replaced with POFA. It is reported that the maximum strength gain occurred at the replacement level of 30% but further increase in the ash content would reduce the strength of concrete gradually. However, the result of POFA performance once added in concrete still yet to be studied. Besides that, added that increasing in fineness of POFA would lead to greater concrete strength development than the coarser one (Awal & Hussin, 1996).

2.6 Pozzolanic as Cement Substitute

There is no disbelief that the inclusion of pozzolanic material, both naturally occurring or artificially made, as a partial cement replacement passes on significant enrichment of the basic characteristics of the resulting mass either in its fresh and hardened states. Nowadays, of all the silicon by-products, POFA are possibly the most widely used globally. Added to this is the fact that POFA makes considerable changes to the strength and durability aspects of concrete the are well documented in national codes and standards.

Separately from industrial waste, ashes from agricultural source like rice husk, coconut husk, palm oil husk. peanut shell or fiber shell etc, have been used for making cement substitutes (Bentur et al., 1986). Among them, rice husk ash (RHA) is highly rich and has been distinguished as the most active pozzolan in making high performance concrete and cement products. Previously, numerous works have been carried out to look into the various aspects of ashes with pozzolanic behavior, and in many parts of the world these materials have already been known as supplementary cementing materials.

2.7 Applications of Pozzolanic in Concrete

Most of the concrete produced today are a multi component product containing one or more admixtures in addition to the four basic component which is cement, water, fine aggregate and coarse aggregate. For every component, one usually has several choices that could influences the cost of the end product and its behavior in service. Among the constituent components, however, cement or cementitious materials as a whole play a vital role in producing strong and durable concrete. For many purposes a pozzolan has been regarded as a substitute for a proportion of cement in a concrete.

Incorporation of this pozzolanic material involving replacement of a part of the Portland cement with excess weight of fly ash, replacing also part of the aggregate would to creation a more economical concrete (Samarin et al., 1983). The contribution of pozzolana material in concrete towards improvement of concrete durability has also been highlighted (Mehta, 1988) and (Hoff, 1992) who reported that the incorporation of pozzolanic material such as fly ash, silica flume, and natural pozzolans in concrete contribute to the formation of the denser binder which inhibits the migration of the sea water into concrete. Other researcher Awal & Hussin (1996) proved that adding POFA for production of concrete would be able to increase the resistance of concrete toward sulphate and acid attack. The role of pozzolan towards improving the properties of concrete has become significant to the extent whereby there are researcher such as (Dunstan, 1986) who stated that fly ash should be considered to be the fourth ingredient in concrete, that is in addition to the aggregate, cement and water, and not as a replacement of the cement. Conclusively, whatever is the mode of application all the methods can result in a significant improvement and optimization of certain properties of both fresh and hardened concrete.

2.8 Pozzolanic Reaction and Its Significance

It is well known that pozzolanic reaction can only take place with the existence of calcium hydroxide that is produced from hydration process reacting with pozzolanic material in the presence of moisture. The extent of the pozzolanic reaction depends on the fineness of the pozzolanic material as well as the amount of silica in this material. In this studies, integration of pozzolanic material as a cement replacement for production of concrete improves the properties of the concrete in terms of strength or durability. On overall, application of this material for construction material able to reduce cost of the material and also provides mean of using this pozzolanic material which might end up in landfill if it is not put to any use.

2.9 Particle Size Distribution

It is a well known fact that the increase in the fineness of pozzolana material would lead to significant increase in strength. The extremely fine particles in concrete act as lubricant in the concrete mix and permits a reduction in water content, thereby, increasing strength. Additionally. The ash spheres with their multi sized spherical morphology promote a high packing density of plastic concrete. The influence of ash fineness toward strength development of concrete has been investigated by many researchers. The fineness of pozzolanic ash also tends to affect both the fresh and hardened state properties of concrete (Awal, 1998). Generally, the ash used as pozzolanic material need to produced in a finer size so that can function effectively in increasing the strength of concrete.

2.10 Length of Curing

Curing is one of the important steps need to be applied to exploit all potential capabilities of the cement used in the concrete mix. This procedure consist of providing an environment where temperature and moisture movement from and into the concrete is controlled. This procedure is essential for promoting the hydration of cement to ensure continuous strength development of concrete. However, curing of pozzolanic concretes or mortars, however, needs more care than that with Portland cement. Also the strength development of concretes containing pozzolans is more adversely affected by very short curing periods under water than the plain one (Neville, 2005).

2.11 Pozzolan Content

Pozzolanic concretes need an optimum content of pozzolan to attain the best performances. The amount of pozzolan material used varies depending on the desired properties to be achieved such as better durability or other aspects. Studies conducted on POFA utilization in concrete found that only certain amount of POFA integrated as partial cement replacement could improve the strength of concrete to be higher than the plain concrete. According to Awal (1998), integration of 30% POFA would produce concrete of higher strength and better durability in comparison to plain concrete. Another researcher (Hussin et al., 2008) discovered that inclusion of 20% POFA would produce concrete having highest strength as compared to any other replacement level. The variation in the replacement level for achievement for best performing concrete mix varies due to the difference in chemical composition of the POFA used in this study. As a conclusion, POFA being a pozzolanic material could not be used in a very high amount since it would give negative impact towards strength development of concrete.

2.12 Chemical Attack

The chemical attack on concrete may cause destructive expansion and decomposition of the cement paste leading to severe deterioration. Actually, the extent of concrete deterioration depends upon the nature and concentration of the substances in solution as well as the condition of the concrete itself. The more common forms of chemical attack on concrete are leaching out of cement and action of sulphates, sea water, and acids of inorganic or organic sources. Deterioration by chemical reactions also involves in alkali aggregate reaction but this occurs between the alkalis in cement and reactive silica present in certain aggregates. However, the durability of the concrete toward chemical attack could be improved through formation of dense and well compacted concrete other than integrating pozzolanic ash as partial cement replacement material.

2.13 Sulphate Attack

The deterioration of cement based building materials by sulphate attack has long been recognized as a significant durability problem. Sulphate attack on concrete is complex phenomenon that involves a series of primary and secondary chemical reactions, some of which are interrelated. Soluble sulphate of calcium, sodium, magnesium and ammonium present in soil and ground water are harmful to concrete since these element can lead to swelling and consequently cracking of concrete. Other situations where sulphate can attack concrete are sea water, industrial effluents, fertilizer applications, and acid rain water (Mehta, 1986). The degree of deterioration, however, depends on the intensity of the attack as well as on the characteristics of the concrete.

According to Lea (1970) when a cementitious material is exposed to a sulphate environment, the sulphate attack take places as a sequence of the following process.

a) The first process, controlled by the permeability of the cement concrete matrix, is the diffusion of the sulphate ions into the pores of the matrix which is responsible for reaction between the constituents of cement and concrete with aggressive sulphate ions.
b) The second process is the reaction between environmental sulphate ions and crystalline calcium hydroxide present in the hydrated cement to yield crystalline calcium sulphate (gypsum).
c) In the third process, sulphate ions react with hydrated tricalcium aluminates to form calcium suiphoaluminate (ettringite).

Research conducted by Mather (1982) and Yeginobali & Dilek (1996) although based on short term studies suggest that silica fume has the potential to increase the resistance of concrete against sulphate attack. In addition, low calcium fly ashes have been reported to be effective mineral admixtures for combating sulphate attack on concrete (Mehta, 1986). Upon exposure to sulphate environment, the superiority of POFA when added as partial cement replacement in lightweight concrete (Hussin et al., 2008) and normal concrete (Awal, 1998) also comfirmed that POFA blended cement concrete performed better than the specimen formed of 100% OPC. On overall, the ability of pozzolanic material to increase the sulphate resistance of concrete when used as one of the mixing ingredient for concrete manufacturing has been well established in many studies.