SELF HEALING CONCRETE

BY INCORPORATING PALM OIL FUEL ASH (POFA)

AS CEMENT REPLACEMENT MATERIAL

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ABSTRACT

Malaysia as the world largest exporter of palm oil has been facing problem in disposing palm oil fuel ash (POFA), a by-product of palm oil mill. Previous researchers were revealing the potential of this finely ground waste as a partial cement replacement in reacted as pozzolans to produce a self healing concrete. In this study, the effectiveness using POFA as cement replacement material towards self healing of concrete were investigated. Four series of mix formulation in producing POFA concrete with different percentage of cement replacement namely 0%, 10%, 20% and 30% were designed. All specimens were subjected to compressive strength due to 7, 28, 60 and 90 days cured in water. In addition, the UPV test was conducted in order to monitor self healing progress of POFA concrete specimens due to hairline crack. The specimens were tested at different curing types subjected to UPV test. It was found that, the concrete with 20% of POFA recorded highest compressive strength compare to those mixes. It also revealed that, the UPV values were increases correspondingly to curing ages when POFA concrete immersed in water curing type. It shows the water curing were the effective mechanism towards self healing process.

ABSTRAK

Malaysia sebagai salah satu pengeksport kelapa sawit terbesar di dunia menghadapi masalah pelupusan abu terbang kelapa sawit (POFA), salah satu produk sampingan dari kilang kelapa sawit. Para penyelidik telah menemui bahawa abu terbang yang dikisar halus untuk menggantikan sebahagian simen dapat mengaktifkan tindakbalas pozzolana untuk penghasilan konkrit pulih sendiri. Kajian ini menunjukkan keberkesanan POFA untuk menggantikan simen dalam konkrit pulih sendiri. Terdapat empat siri formula campuran untuk menghasilkan konkrit POFA yang menggantikan simen dengan peratusan yang berbeza iaitu 0%, 10%, 20% dan 30% dikendalikan. Semua sampel diuji dengan ujian mampatan pada hari ke 7, 28, 60 dan 90 yang telah direndam di dalam air. Selain itu, ujian UPV turut dijalankan untuk memantau proses pemulihan sendiri konkrit yang mempunyai retakan halus tersebut. Sampel yang diuji adalah mengikut proses kuring yang telah di tentukan. Hasil ujian menunjukkan bahawa konkrit yang mempunyai 20% kandungan POFA merekodkan keputusan ujian mampatan yang paling tinggi berbanding dengan peratusan lain. Selain itu, nilai UPV meningkat dari hari ke hari semasa pemantauan dibuat dan kuring air adalah yang terbaik di antara tiga jenis kuring yang lain. Ini menunjukkan bahawa kuring air adalah kuring yang paling terbaik untuk proses pemulihan konkrit.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Palm oil industry in Malaysia is one of the sectors famously chosen to be developed commercially in several tropical countries located in Asian region. The development on agricultural-based industry in Malaysia since previous century has able to generate and become the largest producer focusing on palm oil industry. Basiron and Simeh (2005) reported that Malaysia has become the current number one palm oil around Asian which the development must be maintain its lead position over the next one and the half decades producing 18 million tones or 42% of the world palm oil in 2020.

It is predicted that the quantity of palm oil fuel ash (POFA), a profitless by-product generated by palm oil mill will increase as the production of palm oil continue to grow over the year. Therefore, it is anticipated that the success in discovering the utilization of this material in any type of material making process would be able to reduce quantity of waste thrown and assist palm oil industry to be more ecological friendly sector. Glancing through the history of this material introduced in construction area, it has been Malaysian researcher who managed to prove that this material possesses pozzolanic properties (Abu, 1990). Abdul Awal and Hussin (1997) have proved that this waste could be used as partial cement replacement in concrete for production of stronger and more durable construction material. Succeeding the findings, more researchers have integrated POFA as one of mixing ingredient in the mix to produce new type of concrete such as high-strength concrete (Sata et al., 2004) and lightweight concrete (Mat Yahaya, 2003).

Palm oil fuel ash (POFA) is a by-product from burning process in thermal power plant, which palmnut and fiber of palm are burnt at temperature about 300-400^0 Celcius. Each year more than 100,000 tons of POFA has been disposed and tended to increase annually. From the study of the chemical composition, it was found that the POFA could be used as a pozzolana. In this study, the quality of POFA was improved by grinding until the median particle sizes were 19.9 and 10.1 microns. The POFA were used to replace Portland cement (OPC) up to 30% by weight of cement. After that, water curing process and compressive strength test of specimens at the age of 7, 28, 60 and 90 days will be monitored and recorded.

1.2 Rational of the Study

The accelerated developments in concrete research over the past 20 years have opened new and more proficient utilization of components available in nature, including industrial waste. The thrust in this accelerated activity has been made or justified because of the economical gains in producing stronger structures that are smaller in component dimensions while larger in resulting space availability.

In recent years, studies have been carried out by various researchers in using waste generated from the agricultural and industrial activities as partial replacement of cement in making concrete (Tay and Show, 1994).Many researchers have studied the use of agro-waste ashes as constituents in concrete. Their results have revealed that these agro-waste ashes contain high amount of silica in amorphous form and could be used as a Pozzolanic material (Tangchirapat and Saeting, 2007).

The consideration usage of the Palm Oil Fuel Ash (POFA) which possesses Pozzolanic material in self-healing concrete is to reduce the excessive wastage of the 100,000 tons of POFA has been disposed and tended to increase annually (Tangchirapat and Saeting, 2007). Rather than exposed as wasted materials or fill embankment materials, hence the wastage of the POFA apparently use in concrete as replacement of partial cement quantity. One other of the main concern is the emission of CO_2 during the hardening process from the chemically calcinations of the limestone can be reduce and apparently the positive significance is the greenhouse effect can be reduced worldwide. Besides that, quantity of the cement for concrete can be reduced about 20% until 30%.

1.3 Problem Statement

Concrete is the most widely used man-made construction materials. It is obtained by mixing cement, water, aggregate and admixture (small quantity). The problem with concrete is crack normally happened at the concrete structure such as beam, column, foundation and others structure element which can causing concrete failure occurred by the shrinkage, overload, rapid changing temperature and settlement above ground level.

It can be outlined where self-healing concrete incorporating palm oil fuel ash (POFA) as an alternative to avoid creeping on hardening concrete. The hairline creep usually occurs during the maturing periods of concrete. Hence, the self-healing concrete is expect to be able repairing it own creep within the curing process. Since the engineers and expertise always faced this problem for everyday during producing the high financial system loss to prevent this problem occurred, it is best to study the effectiveness of this POFA to perform in concrete replacing the cement within the suitable percentage of replaced by POFA up to 30%. Beside the main problem of hairline creep, the emission of the CO_2 expected to reduce and avoiding the greenhouse effect from rapidly happens nowadays.

1.4 Objectives of Study

The objectives of this study are:-

i. To study the effectiveness using POFA in self-healing concrete process

ii. To study mechanism of self-healing concrete incorporating POFA

iii. To obtain optimum percentage of POFA in concrete mixture

1.5 Scope of Study

This study were focused on the investigation of the concrete containing palm oil fuel ash (POFA) substituted as ordinary Portland cement (OPC) replacement. The limitation on this study are to determine the effectiveness of self-healing concrete incorporating POFA (POFA concretes) as pozzolanic material with different percentage of POFA subjected to different curing types. The different percentages of POFA used were calculated based on total weight of the OPC which is 0%, 10%, 20% and 30%. All the specimens were labeled as POFA-0, POFA-10, POFA-20 and POFA-30 respectively. After designation of the mix proportion, the concrete were cast into the standard steel mould with dimensions of 150 mm x 150 mm x 150 mm. The POFA-concretes where cured in water will be test due to compressive strength. The compressive strength test was accordance to ASTM C39 / C39M – 09a. On the other hand, the POFA-concretes specimens were subjected to ultrasonic pulse velocity (UPV) were cured at 7, 28, 60 and 90 days with different type of curing.

There are four (4) types of curing namely water curing, air curing, wet and dry curing and control room curing. Each type of curing has its own possession in term of humidity, dryness, temperature and environment condition. Concrete with grade 30 were designed and poured into standard cast iron mould. After concrete were hardened at 24 hours, the concrete specimens were test under the compressive load to create pre-crack (hairline crack) on the surface of the sample for UPV test. This test will be monitored cautiously to avoid the concrete cube over-cracked. After the pre-crack process, the sample were cured into four different types of curing process which is air curing, water curing, wet and dry curing and control room curing correspondingly for self-healing concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Large number of researches (Mehta, 1983; Malhotra et al., 1992; Massazza, 1993 and Nagataki, 1994) conducted since last century has provided a wealth of information on composition and characteristics of pozzolans and their effects on properties of concrete. However, published literatures on the performance of concrete containing palm oil fuel ash which started last two decades are not many. The objective of this thesis is to present a durability of high strength concrete in particular, from the viewpoint on providing scientific explanations for some of the phenomenological observations. This is needed to encourage the proper use of new cement substitutes in cement and concrete industry.

Firstly, a short review of chemical reactions, considered responsible for setting and hardening of Portland cement, will be given. This will be followed by thedescription of pozzolans and pozzolanic reactions. The rest of chapter includes the performance characteristics of concrete containing the pozzolanic materials on different aspects of durability in terms of chloride penetration, Sulphate attack and acid attack.

2.2 Cementitious Reaction of Portland Cement

Calcium combination with silica, alumina and iron oxide is essentially of crystalline compounds of the Portland cement's consists. These compounds are usually regarded as the major constituents of cement. The actual quantities of the various compounds vary considerably from cement to cement, and in practice different types of cements are obtained by suitable proportioning of the materials. Along with the main compounds, there exist minor compounds such as SO_3, MgO, K_2O and Na_2O, which usually amount to not more than a few percent of the weight of cement.

The compounds of Portland cement clinker are anhydrous, but when water is added the minerals begin to ionize, and the ionic species form hydrated products of low solubility that precipitate out of the solution. The main product of hydration of silicate mineral is a calcium silicate hydrate (C-S-H) of colloidal dimension that, at early age, under a scanning electron microscope, usually shows up as an aggregation of very fine grains partly inter-grown together. The structure of C-S-H is not constant in space and time.

It adopts a variety of morphologies, some based on thin sheets to give fibrous or honeycomb structures at early ages, others with a more compact structure (Reinhardt, 1995). It is highly cementitious and constitutes about 60 to 65 percent of the total solids in a fully hydrated Portland cement. The other product of hydration of the silicate minerals is about 20 percent calcium hydroxide (CH), which usually occurs as large hexagonal crystals, and contributes little to the cementitious properties of the system. Also, being relatively most soluble and alkaline than the other hydration products, it is easily subjected to attack by water or acidic solutions, thus reducing durability of Portland cement systems to such environments (Mehta, 1983). Indeed, the hydration of Portland cement and the reactions involved in it are vast and quite complex in nature.

2.3 Cement Replacement Materials

Cement replacement materials (Illston and Domone, 2001) are those which used as a substitute for some of the Portland cement in a concrete; partial cement replacement materials are therefore a more accurate but less convenient name. There are also a number of other names for this group of materials, including supplementary cementitious materials, cement extenders, mineral admixtures, mineral additives, latent hydraulic materials or, simply, cementitious materials.

Several types of materials are common in use, some of which are by-products from other industrial processes, and hence their use may have economic advantages. However, the main reason for their use is that they can give a variety of useful enhancements of or modifications to the concrete properties. All the materials have two common features; their particle size range is similar to or smaller than that of Portland cement, also they become involved in the hydration reactions.

They can be supplied either as individual materials and added to the concrete at mixing, or as pre-blended mixtures with the Portland cement. The former case allows choice of the rate of addition, but means that an extra material must be handled at the batching plant; a pre-blended mixture overcomes the handling problem but the addition rate is fixed. Pre-blended mixtures have the alternative names of extended cements, Portland composite cements or blended Portland cements. Generally, only one material is used in conjunction with the Portland cement, but there are an increasing number of examples of the combined use of two or even three materials for particular applications.

The incorporation of Cement Replacement Materials leads to a rethink about the definition and use of the water/cement ratio, which is an important controlling factor for many properties of hardened cement paste and concrete. It is generally accepted that this should remain as the ratio of the amount of mix water to that of the Portland cement, and the term water/binder ratio should be used for the ratio of the amount of mix water to the sum of the amounts of all of the cementitious materials, i.e. the Portland cement plus the Cement Replacement Materials.

2.4 Pozzolanic Materials

A pozzolana is a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties (Neville, 2005). Figure 2.1 and 2.2 will show the example of pozzolanic material and its condition under microscope.

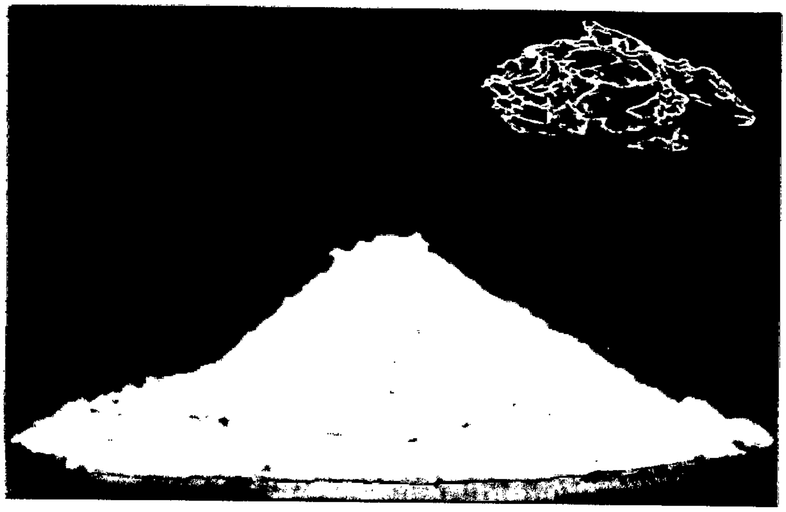

Figure 2.1: Example of White Pozzolanic
(Source: www.bombayharbor.com)

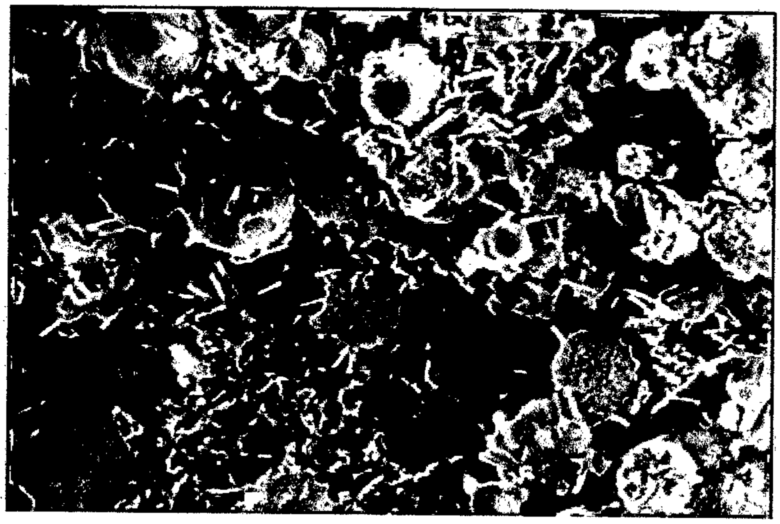

Figure 2.2: Pozzolanic Material under Microscope
(Source: www.hepco.co.jp)

2.5 Pozzolanic Behaviour

A common feature of nearly all Cement Replacement Materials is that they exhibit pozzolanic behavior to a greater or lesser extent, and so we will define this before discussing the individual materials (Illston and Domone, 2001). A pozzolanic material is one which contains active silica (SiO_2) and is not cementitious by itself, but will, in a finely divided form, and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form cementitious compounds. The key to the pozzolanic behavior is the structure of the silica; this must be in a glassy or amorphous form with a disordered structure, which is formed in rapid cooling from a molten state. A uniform crystalline structure which is formed in slower cooling, such as is found in silica sand, is not chemically active. Naturally occurring pozzolanic materials were used in early concretes, as mentioned in the Introduction to this part of the book, but when a pozzolanic material is used in conjunction with a Portland cement, the calcium hydroxide that takes part in the pozzolanic reaction is that produced from the cement hydration. Further quantities of calcium silicate hydrate are produced in Equation 2.1

$$2S + 3CH \rightarrow C_3S_2H_3 \qquad \text{[Equation 2.1]}$$

The reaction is clearly secondary to the hydration of the Portland cement, which has lead to the name 'latent hydraulic material' in the list of alternatives above. The products of the pozzolanic reaction cannot be distinguished from those of the primary cement hydration, and therefore make their own contribution to the strength and other properties of the hardened cement paste and concrete.

2.6 Types of Pozzolanic Materials

The performance of pozzolanic material when added as a mixing ingredient in a concrete differ base on their origin, nature and characteristics. It may be interesting here to speculate why rice husk ash (RHA) is the most reactive of all the supplementary cementing materials, in spite of the fact that condensed silica- fume and many fly ashes and granulated blast-furnace slag also contain large amounts of non-crystalline reactive minerals. Mehta (1992) has the explanation for the above speculation. According to Mehta, these materials are obtained from rapid cooling or condensation of droplets of high-temperature melts. The surface of products formed by condensation of a melt is not micro-porous, therefore, an induction period is needed to activate the surface in the alkaline environment provided by the hydration of Portland cement. The same researcher added that in the case of RHA particles with highly micro-porous surface, a long induction period is not necessary for the surface reactions involving the formation of C-S-H and hydrous silica.

There are many types of the pozzolanic material (Illston and Domone, 2001). The main cement replacement materials in use world-wide are:-

i. Pulverized fuel ash (PFA); called fly ash in several countries; the ash from pulverized coal used to fire power stations, collected from the exhaust gases before discharge to the atmosphere; only selected ashes have a suitable composition and particle size range for use in concrete
ii. Ground granulated blast furnace slag (GGBS); slag from the scum formed in iron smelting in a blast furnace, which is rapidly cooled in water and ground to a similar fineness to Portland cement;
iii. Condensed silica fume (CSF); often called microsilica, extremely fine particles of silica condensed from the waste gases given off in the production of silicon metal;
iv. Calcined clay or shale; a clay or shale heated, rapidly cooled and ground;

v. Rice husk ash; ash from the controlled burning of rice husks after the rice grains have been separated;

vi. Natural pozzolans; some volcanic ashes and diatomaceous earth.

2.7 Origin of Palm Oil Fuel Ash

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 (Abdullah and Hussin, 2006).

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 (Abdullah and Hussin, 2006).

2.8 Pozzolanicity of Palm Oil Fuel Ash

The pozzolanicity of any material is closely related to the ability of silica to react with calcium hydroxide to produce calcium silicate hydrate. For an assessment of pozzolanic activity with cement, the method of pozzolanic activity index which determines the totals activity of pozzolana (Neville, 2005).