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

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ABSTRACT

With growing concern in the past decade over attributes to poor quality of concrete due to the durability especially in corrosion problem, various parameters and testing were suggested for improvement the quality of concrete composite. The development and use of blended cement is growing rapidly in the construction industry mainly due to considerations of cost saving, energy saving, environmental protection and conservation of resources. Demand for the high durability and environmental friendly nowadays developed POFA as an alternative material to replace cement in construction field. The use of POFA to replace a portion of cement has result significant saving in the cost of cement production. In this research, the durability towards chloride penetration in concrete was assessed. The influence of POFA on the corrosion performance of concrete was studied by some accelerated short term technique in sodium chloride solutions. By adopting various activated techniques such as physical and chemical methods, hydration of POFA blended cement was accelerated and thereby improved the corrosion resistance of concrete. Concrete specimen prepared with 10%, 20% and 30% of POFA replacement were evaluated for their impressed voltage test, half cell potential test and chloride binding capacity test and the testing results were compared with those for OPC concrete without POFA. All the specimens were cured for 28 days before the testing was done. The study confirmed that level of 20% POFA replacement as cement improved the corrosion resistance properties. Therefore, POFA can be use as a cement replacement material to improve the corrosion resistance of concrete. At the same time, the problem of disposal of palm oil industry can be solved and new product can be produced to generate economic resources.

ABSTRAK

Dengan kebimbangan yang semakin meningkat dalam dekad yang lalu ke atas ciri-ciri mutu konkrit dari segi ketahanan terutama dalam masalah hakisan, pelbagai parameter dan ujian telah dicadangkan untuk penambahbaikan kualiti komposit konkrit. Pembangunan dan penggunaan simen campuran berkembang pesat dalam industri pembinaan terutamanya disebabkan oleh pertimbangan penjimatan kos, penjimatan tenaga, perlindungan alam sekitar dan pemuliharaan sumber. Permintaan untuk ketahanan yang tinggi dan mesra alam sekitar menjadikan POFA kini dibangunkan sebagai bahan alternatif untuk menggantikan simen di bidang pembinaan. Penggunaan POFA untuk menggantikan sebahagian simen mempunyai hasil penjimatan yang ketara dalam kos pengeluaran simen. Dalam kajian ini, ketahanan terhadap penembusan klorida dalam konkrit telah dinilai. Pengaruh POFA kepada prestasi hakisan konkrit telah dikaji oleh beberapa teknik kecepatan jangka pendek dalam larutan natrium klorida. Dengan menggunakan pelbagai teknik pengaktifan, seperti kaedah fizikal dan kimia, penghidratan campuran simen POFA telah dipercepatkan dan ketahanan kakisan konkrit adalah lebih baik. Spesimen konkrit disediakan dengan 10%, 20% dan 30% daripada penggantian POFA aktif dan telah dinilai untuk ujian teknik kesan voltan, ujian keupayaan separa sel dan ujian penyikat kapasiti klorida dan keputusan ujian dibandingkan dengan konkrit OPC tanpa POFA. Semua specimen telah direndam selama 28 hari sebelum ujian dilakukan. Kajian telah mengesahkan penggantian 20% POFA simen meningkatkan sifat rintangan kakisan. 20% POFA merupakan campuran optimum bagi penggantian cement untuk mendapatkan rintangan pengaratan yang terbaik. Oleh yang demikian, POFA boleh digunakan sebagai bahan gantian simen untuk meningkan ketahanlasakan konkrit terhadap pengaratan. Dalam pada masa yang sama juga, masalah pembuangan sisa daripada industry kelapa sawit dapat diselesaikan dan seterusnya dapat menghasikan produk yang baharu bagi menjana sumber ekonomi.

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LIST OF ABBREVIATIONS

Al_2O_3	Aluminium Oxide
ASTM	American Society of Testing Materials
AS_2O_3	Arsenic Trioxide
BS	British Standard
CaO	Calcium Oxide
$CaCl_2$	Calcium Chloride
$CaCO_3$	Calcium Carbonate
$Ca(OH)_2$	Calcium Hydroxide
Cl^-	Chloride
CO_2	Carbon Dioxide
Cr_2O_3	Chromium Oxide
Fe	Iron
Fe_2O_3	Iron Oxide
$Fe(OH)_2$	Iron Hydroxide
H_2O	Water
K_2O	Potassium Oxide
MgO	Magnesium Oxide
MnO	Manganese Oxide
MoO_3	Molibdenum Trioxide
MS	Malaysian Standard
NaCl	Sodium Chloride
Na_2O	Sodium Oxide
Nb_2O_5	Neobium Pentoxide
NiO	Nickel Oxide
OCP	Open Circuit Potential
OPC	Ordinary Portland Cement
POFA	Palm Oil Fuel Ash
P_2O_5	Phosphorus pentoxide

SCE	Saturated Calomel Electrode
SiO_2	Silica Oxide
SO_3	Sulfhur Trioxide
SrO	Copper Oxide
TiO_2	Titanium Oxide
Y_2O_3	Yttrium Oxide

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Concretes can be defined as composite material produced by combination between cement, usually Portland cement, is mixed with a fine aggregate (such as sand), a coarse aggregate (granite), and water (Zaki Ahmad, 2006). The structure and composition of the cement paste determine the long term performance of concrete and the durability of concrete (Bertolini, Elsener Pedeferri and Polder, 2004). According to Malaysian Journal of Civil Engineering 23(2):1-11, (2011), corrosion is defined as destruction or degradation of material usually happened to metals. Corrosion of reinforcement is a universal problem that effect on durability of concrete structure. Corrosion of the steel bar in concrete remains its most common durability problem. Corrosion problem damage the reinforced concrete structure.

Environment plays an important role in corrosion problem. The conditions which lead to corrosion in concrete structure are becoming understood. Many existing concrete structures nowadays exhibit significant corrosion. Most of the failures of concrete structures cause by corrosion problems (Hands Bohni, 2000). C.L Page and M.M Page prove that besides the Portland cement used in producing concrete, many modern concretes contain various added solid component can be used to make concrete become more durable. Generally, it will reduce the alkali hydroxide concentration produce in concrete. The incorporation of fly ash as a replacement cement material in concrete exerts a very strong influence in reducing permeation capacity, although not necessarily to the same extent in different type of measurement.

Nowadays, recycle material as a replacement concrete material is widely used in Malaysia. Material used like palm oil fuel ash is commonly used as a cement replacement because POFA is the second largest waste in Malaysia. According to Sumadi and Hussin, 1993 stated that the physical properties and chemical properties analysis of POFA shows that POFA is a pozzolanic material that can be used as a cement replacement material. For recent years, use the pozzolan material as a cement replacement material has become common practice. POFA is one of recent pozzolanic material that is used for several economical and environmental reasons. Moreover, the POFA particles react with the calcium hydroxide, producing hydration product that strongly decrease porosity. POFA is used as fine cement and upon hydration it has capability of partially obstruction void and pores. (Y-S Choi et al, 2006).

The influence of pozzolanic material namely Palm oil Fuel Ash (POFA) on the corrosion performance of steel bar embedded in concrete is very impressive. This pozzolanic material can be grouped to Class C and Class F as specified in (ASTM C618-92a, 1994). POFA is moderately rich in silica content meanwhile lime content is very low as compared to OPC 10 (Awal and Hussin 1997). On the other hand, the chemical composition of POFA can be varied due to operating system in palm oil mill. Research from Faculty of Civil Engineering of University Technology Malaysia was successfully discovered that POFA can be considered as replacement materials that are actually used in a construction industry specifically in concrete engineering. The POFA used in concrete production continue to be study by researcher in Asian because of the waste from palm oil mill widely discover in Asian region.

KEYWORDS: *Corrosion, Durability, Palm oil fuel ash, Pozzolanic material.*

1.2 PROBLEM STATEMENT

With growing concern in the past decade over complaints attributes to poor quality of concrete due to the durability especially in corrosion problem in concrete structure, various environmental parameters and testing were suggested for improvement the quality of concrete composite. The pozzolanic material used for reducing the Portland cement content in mortar and concrete paste. The testing include of corrosion test and chloride binding capacity. Corrosion in reinforcement is a common problem that affects the durability and integrity of a reinforcement concrete structure. At the advance stages of corrosion deterioration, the repairing of concrete structure is very costly and time consuming. Some prevention measured can be carried out to prevent the corrosion problem at the earlier stages (Siti Fatimah Abdul Rahman et. al., 2011).

Prevention of corrosion is depends on the properties of concrete. Portland cement blended with the pozzalona should be preferred, because the addition of replacement material as a pozzalona will contribute to hydration reaction and thus the reduction in porosity of the cement paste (Bertolini, Elsener Pedeferri and Polder, 2004). Malaysian Journal of Civil Engineering 23(2):1-11, (2011) stated that, corrosion can also be delayed by using new material which is recommended to resist corrosion such as the application of blended cement in concrete. Therefore, it is also important to conduct a study in corrosion monitoring to predict the quantitative assessment of corrosion risk and to take action on the future (Legal et al. 2004 and Ervin et al. 2009).

There are many methods that have been tried to suggest of delaying the corrosion process. Previous study by Hussain et al. 1994 stated that the quality of concrete can be improved by adding admixture such as volcanic ash, fly ash, ground granulated blast furnace slag and palm oil fuel ash.

1.3 OBJECTIVE OF STUDY

The objectives of the study are:

i. To investigate the corrosion performance by using POFA as a cement replacement material in concrete.
ii. To determine the chloride binding capacity of POFA concrete.

1.4 SCOPE OF STUDY

The purpose of this research is to study on performance of POFA as a cement replacement due to the corrosion resistance in concrete and to study the chloride binding capacity in POFA concrete. The investigation is by comparing the plain concrete with 0% of POFA cement replacement and 10%, 20%, 30% respectively that consist with POFA as a replacement ingredient to concrete.

The corrosion problem was detected by using accelerated test which are; impressive voltage test and half cell test. The impressed voltage technique is an accelerated corrosion testing technique which indirectly gives information about the permeation characteristics of the concrete. While, the performance of chloride binding can be detected by using chloride binding capacity test that determined the free chloride content and bound chloride content.

All of this testing need to be measured under the standards which are Impressed Voltage Test and Half Cell Test interpreted based on ASTM C-876-1994. The Chloride Binding Capacity test was measure under the standard ASTM C-114-2000. This research is conducted at Concrete Laboratory in Universiti Malaysia Pahang (UMP). All specimens have been casting in a cylindrical mould of 80 mm in diameter and 160 mm in height. 28 days of curing time have been conducted in water curing.

1.5 SIGNIFICANT OF STUDY

Since the last decades, concrete plays the important parts 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 material. This research is to investigate and propose the significant of the replacement POFA as a cement material increase the durability of concrete by decrease the corrosion problem. According to Mohd Eriezi (2010), with the use of POFA, the ingress of moisture, oxygen, chlorides, carbon dioxide, and aggressive chemicals are slowed significantly.

The purposes of the study are:

i. Reduce usage of cement content by replacing palm oil fuel ash as a cement replacement in concrete in order to provide corrosion resistance in concrete itself.
ii. To reduce waste from palm oil mill.
iii. To produce economic high durability concrete.
iv. To create new product from palm oil industry and increase economy of country.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete is the material composition that widely used in construction field. This is the mixture of course aggregate, fine aggregate, cement and water. Concrete nowadays changing better by adding with pozzolanic material such as silica fume, fly ash and palm oil fuel ash in order to make it stronger in durability due to pozzolanic reaction occur in concrete mixes.

The development and used of blended cement are widely raised in construction industry mainly due to the consideration of cost saving, energy saving, environmental protection and conservation of resources (Tae-Hyun Ha et. al., 2007). The usage of fly ash in mortar and concrete as a partial replacement of Portland cement appears to constitute a very satisfactory outlet for this industrial by product. The fly ash are used to substitute a portion of a cement give positive result in saving cost of production of concrete (Tae-Hyun Ha et. al., 2007).

Based on Abmad et al., (2008) POFA have a potential become a good replacement material comparing to other waste because it 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.

2.2 CONCRETE INGREDIENT

Concrete has been the construction material used in the large quantity for several decades besides using timber or steel materials. Concrete are popular used in the construction because of the properties of concrete itself as well as the acceptable costing. Material called concrete is made of from four basic ingredient which are course aggregate, fine aggregate, cement and water (Sandor Popovic, 1992).

2.2.1 Coarse Aggregate

Concrete aggregate is more granular usually inorganic material consists of stones and granite. The used of aggregate in concrete is to reduce the amount of cement which is important for technical and economical perspective. Aggregate can be classified in several different ways according to their natural and manufactured such as the specific density and sizing. The properties of course aggregate are determined by appropriate testing such as sieve analysis (Sandor Popovic, 1992). The aggregate size used is 10 mm standard according to MS 29: 1995.

Figure 2.1: Course aggregate size 10 mm

2.2.2 Fine Aggregate

Typically example of fine aggregate used in concrete mixes is sand. Fine aggregate mostly comes in a small particles compared to course aggregate. The dividing line between coarse aggregate and fine aggregate is arbitrary. The standard size of fine aggregate is according to MS 29: 1995.

Figure 2.2: Fine aggregate

2.2.3 Portland Cement

Portland cement has become a most important ingredient in construction material and it is one of the primarily material in concrete mixes. Portland cement is produce from combination between limes containing material such as lime stone. Typical tiny Portland cement numerous microscopic crystals called clinker minerals also known as cement compounds. The various function of concrete need Portland cement of different properties. The properties can be change by altering the cement fineness and properties of cement compound (Sandor Popovic, 1992). The Portland cement used according standard ASTM C1 50 -05.

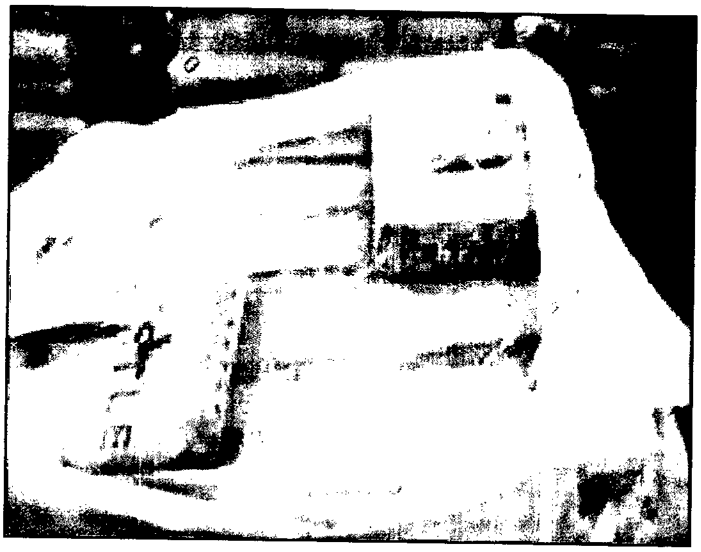

Figure 2.3: Ordinary Portland cement

2.2.4 Water

Water is used in concrete making as mixing in concrete paste, used for cutting of concrete and washing. Impurities may be either dissolved in the water or present in the form of suspensions. Some of these impurities such as sugar, tannic *acid,* vegetable matter, oil, and sulfates, may interfere with the hydration of the cement, thus delaying setting and reducing the strength of the concrete. These effects vary markedly with the brand and type of cement used as well as with the richness of the mixture. Specifications for tolerable maximum amounts for impurities in mixing water are available (Sandor Popovic, 1992). Portable water use in the present study according to standard MS 28: 1985.

2.3 DURABILITY OF CONCRETE

Vijay R. Kulkarni state that, while this spectacular growth has been occurring in concrete production, the problem of early deterioration of some of the reinforced and pre stressed concrete structures has also come to the forefront in recent years.

Neville state that, durability of reinforced concrete structures is a pervasive and universal problem. Many concrete structures deteriorate prematurely, and repair and maintenance costs amount to substantial proportions of public and private sector budgets. Durability problems cover a wide range including attack by external destructive agents (e.g. sulphates), internal material incompatibilities (e.g. alkali-aggregate reaction), and aggressive environments such as freeze-thaw.

Durability problems related to environmental causes including steel corrosion, delamination, cracking, carbonation, sulphate attack, chemical attack, scaling, spalling, abrasion and cavitation.

2.4 CORROSION

Corrosion of reinforcement is a worldwide problem that affects durability and integrity of reinforced concrete structures. Repairing deteriorated reinforced concrete structures at an advanced stage is very costly and time consuming. It is more advantageous if corrosion can be detected at an earlier stage so that some preventive measures can be carried out. Monitoring of reinforcement corrosion in concrete can be achieved by embedding corrosion sensor within the concrete cover (Malaysian Journal of Civil Engineering 23(2):1-11 (2011).

By far the most serious of corrosion problem affecting reinforcement steel is the introduction of chloride salt as contaminants of the concrete, which can occurs either when the materials is manufactured during its subsequent exposure to a chloride-laden environment (C.L Page and M.M Page, 2007).

2.4.1 Corrosion as an Electrochemical Process.

Based on the Hans Bohni, 2000, for steel concrete, the corrosion of metal occurs according to the following reaction:

Anodic reaction: $2Fe \rightarrow 2Fe^{2}+ 4e^{-}$

Cathodic reaction: $O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$

Sum of the reaction: $2Fe + 2 H_2O + O_2 \rightarrow 2Fe (OH)_2$

The quality of corrosion rate is depends on several factors which are moisture content and resistivity of concrete, temperature, oxygen availability and pH of pore water. The chloride content itself has a minor influence on the corrosion process.

2.5 THE INFLUENCE OF MOISTURE CONTENT OF CONCRETE

Besides, availability of oxygen in the air affects the permeability of the moisture content of the concrete. Porous material such as concrete may absorb water from the air. For the absorption process and desorption processes the determining factor are the pore structure which is the void in concrete. Since the diffusion of CO_2 is low at the high moisture content of the concrete and the carbonation reaction needs water there is a maximum rate if carbonation at a medium range of relative humidity (Houst Y F and Wittmann F H, 1994).

2.6 CHLORIDE INDUCE CORROSION

It was found that the rapid ingress of chloride into concrete is caused by capillary suction of chloride containing water. Besides, wetting and drying of the concrete speed up the chloride ingress (Hans Bohni, 2000).

At the higher chloride content, chloride will induce corrosion. Early research work suggested a critical value of 0.4% chloride by mass of cement (Rizchart 1969) or the ration of critical chloride/hydroxyl ion is 0.6 (Hunkeler 1994, Breit 1997).

However, since free chlorides in the pore water dominate the driving force (i.e. concentration difference) for diffusion, and the ratio between free and total chlorides is not constant, the resulting diffusion coefficients may be significantly incorrect. Arya et al (1990) investigated the chloride binding was classified into two types ordinary Portland cement (OPC) with the same C_3A content and a sulphate resistant Portland cement (SRPC). 1% $Cl^-$was added as NaCl (w/c = 0.50) and the paste cured for 28 days prior to testing. The chloride binding was considerably less in the SRPC compared with OPC, but there was a significant difference between the two OPCs as well, which was not acceptably explained.

Chloride ions originated from sea water or other sources may penetrate through the pore by diffusion or may have direct access through cracks to the interior of the concrete. Although cement has a natural ability to bind chloride ions, but not all the chloride ions can be bound. There will always existed dissolution equilibrium between bound chlorides and free chloride ions in the pore water. Only the free chloride ions are relevant to the corrosion of the reinforcement (The 3rd ACF International Conference-ACF/VCA 2008).

The mechanism of chloride attack was proved by the 3rd ACF International Conference-ACF/VCA 2008 that chlorides can enter into concrete by both absorption and diffusion processes. A relatively dry concrete surface will promote chloride to enter into the concrete. Process of capillary absorption is responsible for chlorides in solution to enter into the concrete matrix. Once the concrete becomes saturated due the capillary absorption, the process of diffusion will then kick in. Due to Fick's law of diffusion, chloride ion will diffuse through the concrete mass as there will be a concentration gradient of chloride ions from outer surface to the inner part of concrete, closer to the reinforcement bars.

2.7 CARBONATION INDUCE CORROSION

Concrete faces durability problem due to carbonation effect. Carbonation-induced corrosion often occurs on areas of building facades that are exposed to rainfall, shaded from sunlight, and have low concrete cover over the reinforcing steel. Carbonation of concrete also lowers the amount of chloride ions needed to promote corrosion. (Tekeste Teshome Gebregziabhier, 2008)