THE EFFECT OF ULTRAFINE PALM OIL FUEL ASH (UPOFA) ON CHLORIDE RESISTANCE OF CONCRETE

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ABSTRACT

In conjunction with the rapid development of palm oil industry, huge amount of waste generated which end up in landfill and extra cost paid to reduce its impact on our environment. Among the waste, the palm oil fuel ash (POFA) is well known as it contains pozzolanic property that has potential to promote the performance of concrete. Many researches had been carried out to study the mechanical performance of concrete containing POFA. In this study, the ultrafine palm oil fuel ash (UPOFA) was utilised in order to know its effect on the basic mechanical properties and corrosion resistance of blended concrete. The POFA was ground to reach median size of about 5 μm. Four mix of concrete was prepared by partially replacing 0 %, 10 %, 20 % and 30 % of Ordinary Portland Cement with UPOFA. All specimens were water cured for at least 28 days in water curing tank before subjected to lab tests. The specimens were tested for compressive strength, porosity and chloride resistance property through accelerated test and salt ponding. The accelerated chloride test employed was impressed voltage test, half-cell potential. Based on the test result, the concrete with 30 % of UPOFA content show better compressive strength, lower porosity and longer time to crack. It is found that the concrete with partial replacement of 30 % UPOFA to concrete also delays the corrosion to happen on steel bar through half-cell potential test. Besides, the concrete containing 30 % UPOFA as partial cement replacement shows lowest free and total chloride content at depth of 21 mm to 25 mm in concrete as compared to other specimen. From this study, the concrete with 30 % of UPOFA as partial cement replacement material shows the best basic mechanical property and chloride resistance.

ABSTRAK

Perkembangan pesat dalam industri minyak kelapa sawit, sisa-sisa terhasil daripada industri ini kebanyakan dihantar ke tapak pelupusan dan kos tambahan perlu dibayar untuk mengurangkan kesan terhadap alam sekitar. Antara sisa-sisa industri ini, abu bahan api kelapa sawit (POFA) mengandungi ciri pozzolana yang berpotensi untuk meningkatkan prestasi konkrit. Banyak kajian telah dijalankan untuk mengkaji prestasi mekanik konkrit yang mengandungi POFA. Dalam kajian ini, abu bahan api minyak sawit ultrahalus (UPOFA) telah digunakan untuk mengetahui kesan terhadap kekuatan mampatan, keliangan dan ciri rintangan penembusan klorida menggunakan teknik kolam garam dan teknik ujian terpecut. POFA telah dikisar sehingga mencapai saiz median kira-kira 5 μm. Empat campuran konkrit telah disediakan dengan menggantikan 0 %, 10 %, 20 % dan 30 % daripada simen Portland biasa dengan UPOFA. Semua spesimen telah direndam sekurang-kurangnya 28 hari dalam tangki air sebelum ujian makmal dijalankan. Spesimen konkrit telah diuji dalam makmal dari segi kekuatan mampatan, keliangan dan ciri rintangan penembusan klorida menggunakan teknik kolam garam dan teknik ujian terpecut. Ujian terpecut termasuklah ujian teknik kesan voltan, keupayaan separa sel. Berdasarkan keputusan ujian, konkrit yang mengandungi 30 % UPOFA menunjukkan kekuatan mampatan yang lebih baik, keliangan yang lebih rendah dan masa yang lebih lama untuk menghasil retakan di konkrit. Ia didapati bahawa konkrit dengan penggantian separa sebanyak 30 % UPOFA dengan konkrit juga melengahkan hakisan berlaku pada bar keluli melalui ujian keupayaan separa sel. Selain itu, konkrit yang mengandungi 30 % UPOFA separa pengganti dengan simen menunjukkan paling rendah kandungan klorida pada kedalaman 21 mm ke 25 mm konkrit apabila berbanding dengan spesimen lain. Kesimpulannya, konkrit yang mengandungi 30 % UPOFA sebagai separa pengganti simen menunjukkan sifat mekanikal asas yang terbaik dan rintangan klorida yang agak bagus.

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LIST OF ABBREVIATIONS

Al_2O_3	Aluminium Oxide
ASTM	American Society For Testing And Materials
$CaCO_3$	Calcium Carbonate
$CaCl_2$	Calcium Chloride
CaO	Calcium Oxide
$Ca(OH)_2$	Calcium Hydroxide
C_2S	Dicalcium Silicate
C_3S	Tricalcium Silicate
Cl^-	Chloride
CSH	Calcium Silicate Hydrate
DC	Direct Current
Fe_2O_3	Iron Oxide
H_2O	Water
K_2O	Potassium Oxide
MgO	Magnesium Oxide
MS	Malaysia Standard
OPC	Ordinary Portland Cement
P_2O_5	Phosphorus Pentoxide
POFA	Palm Oil Fuel Ash
SiO_2	Silicon Dioxide
SO_3	Sulphur Trioxide
TiO_2	Titanium Oxide
UPOFA	Ultrafine Palm Oil Fuel Ash

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Concrete is a composite construction material which created by mixing cement powder, aggregates, water and admixture at right proportion. The properties of concrete are different from each batch of mixing, due to the changing environmental condition, workmanship and quality of material used. Many researches had been carried out research to improve the performance of concrete as the construction industry is essential all around the world.

Now a day, the steel reinforced concrete is widely used in the construction of buildings and infrastructures due to its excellent durability and cost effectiveness. The tensile behaviour of steel reinforcement increases the load carrying ability of the brittle plain concrete. The reinforced concrete structure must exert sufficient durability to withstand the harsh environment. The failure of reinforced concrete structure may due to overloading and failure of structural material.

The corrosion on steel reinforcement is one of the factors which will decrease the load capacity of the reinforced concrete structure. The corrosion of steel reinforcement can happens under several conditions. The construction defect such as honeycomb, insufficient concrete cover, polluted concrete ingredient and improper joint connection will increase the chance for the steel reinforcement to be corroded. One of the factors causing the corrosion of steel reinforcement in the reinforced concrete structure is due to ingress of chloride.

1.2 PROBLEM STATEMENT

Buildings and facilities are that often subjected to chloride attack, results in reduced lifespan and load carrying capacity. This situation becomes worse for the structure that is built near to the coastal region. Concrete which is exposed to the chlorine attack can lead to corrosion of steel reinforcement, results in reduced strength and integrity. From studies, the palm oil fuel ash (POFA) can increase the concrete compressive strength (Sata et al., 2004) and potential properties towards corrosion prevention. POFA is produced after the burning palm oil shell and husk as fuel in a palm oil mill boiler which will be dumped and incur environmental issues. In this project, the ultrafine palm oil fuel ash (UPOFA) will be added into concrete as the cement replacement and determined its ability to withstand chloride attack.

1.3 OBJECTIVES OF STUDY

The objectives of this research are:

i. To determine the effect of ultrafine palm oil fuel ash (UPOFA) as cement replacement towards the chloride resistance of concrete.

ii. To determine the effect of UPOFA as cement replacement toward concrete porosity.

1.4 SCOPES OF STUDY

There are two types of mix will be produced. The first type of mix is normal concrete. This will be the control sample. Another mix is produced by replacing cement with ultrafine palm oil fuel ash by 10%, 20% and 30%. The median particle size of UPOFA is 5µm (Givi et al., 2010). Two cylinder, one slab and one cube specimens will be produced for each type of variation. Thus, there are 8 cylinders, 4 slabs and 4 cube samples will be produced to conduct this research. The specimens will be cured for 28 days to achieve required compressive strength. Four laboratory tests will be conducted to test achieve the objectives of this research. The testing involved are TGA test, compressive strength test, porosity test, salt ponding, impress voltage test and half-cell potential test.

1.5 SIGNIFICANT OF STUDY

The corrosion of steel in reinforced concrete can be retarded by adding certain amount of UPOFA into the concrete. The usage of UPOFA in retarding chlorine induced corrosion can prolong the lifespan of the reinforced concrete structure and reduce the cost of maintenance. Besides, the POFA generated from the palm oil mill can be reused to optimize the durability of concrete instead of disposing it. The reuse of POFA could reduce the yearly amount of landfill generated from palm oil industry.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is explained the literature of the concrete chloride corrosion. This chapter consists of two sub- section. They are concrete chloride corrosion and concrete with added pozzolanic material.

2.2 CONCRETE

Concrete has become the most popular material used in construction industry decade ago. The advantages of easy handling, lower material cost and required basic labour skill makes concrete the even popular. Concrete has been used in the constructing beams, columns and also foundation. Concrete is formed by mixing cement powder, aggregates and water together. The concrete is graded based on its strength and durability.

The cement powder acts as a binder and filler, which need water to trigger the binding reaction. The aggregates provide strength to the concrete mix. Normally, course aggregate and fine aggregate is used to optimise the strength performance of concrete. The strength of aggregate depends on its composition, shape and size. The well graded aggregates enable the voids created between the coarser aggregate are filled up by finer aggregate. The harden concrete can withstand certain degree of compression force and shear force or tensile force.

Due to advancement of technology and extensive research, steel reinforced concrete had introduced to boost the performance of plain concrete. The high yield steel bar is placed at strategic location to increase the load carrying capacity of concrete structure. For example, the steel bars that run through the whole length of column provide additional buckling resistance. In reinforced concrete beam, steel bars are placed at the bottom of beam to provide additional tension force; thus the beam can carry more loads. The performance of steel reinforced concrete had been proofed since decades ago through researches and practical applications.

2.3 CONCRETE DURABILITY

The concrete durability is not only depends on the compressive strength, cement content and water cement ratio; but also considering the permeability and shrinkage property of concrete. The durability of concrete also can be reduced by the chemical attack due to surrounding environment, inappropriate design specification and poor workmanship (Moradi-Marani et al., 2010).

Besides structural design failure, corrosion of steel reinforcement is another main reason of depleted concrete durability (Montemor et al., 2003). The problem of corrosion had become a worry for past three decades. This problem has led to expensive repairing cost and will causes catastrophic to safety of building occupancy.

Kulkarni (2004) reported that there is an increasing tendency of early sign of distress and damage or premature deterioration happens on concrete structure. He believes this abnormal phenomenon maybe due to the climate changes. Montemor (2003) also think that the structures located near to water or coastal atmosphere have higher chance of early degradation.

2.4 CARBONATION

Carbonation of concrete is a chemical reaction that involves the diffused carbon dioxide gas through the pores of the concrete and reacts with the hydration products, such as calcium hydroxide and calcium silicate hydrate, this reaction process can change the physical and chemical properties of the concrete (Neves et al., 2013). They mentioned that the carbonation process will lower the pH value of concrete. The lowered pH of concrete means the concrete is losing and destroying its alkalinity. The pH of pore solution will drop from 12.6 to lower than 9, thus the naturally occurred passive film oxide layer that protects the steel reinforcement will be destroyed and the process of corrosion commences due to present of pore solution (Chi et al., 2002).

There are two main causes of carbonation to happen and accelerate; which are environment factors and concrete properties. The carbon dioxide gas concentration, occurrence of dry and wet cycle and relative humidity are categorised as environmental factor that induces concrete carbonation. While, the concrete porous structure can activates carbonation and thus influenced the mass transport properties and to the amount of the substance that can be transformed into carbonates (Neves et al., 2013).

Carbonation started with the penetration of atmospheric carbon dioxide into concrete. The atmospheric carbon dioxide reacts with the water presented in concrete pore or from weathering to form carbonic acid and water. The calcium hydroxide ($Ca(OH)_2$) in concrete reacts with the atmospheric carbon dioxide to form calcium carbonate ($CaCO_3$) and water (H_2O). The carbonic acid can neutralise the alkalinity of cement matrix, while water can initiate the corrosion on steel reinforcement. The reaction of atmospheric carbon dioxide with concrete is as shown in following:

$$CO_2 + H_2O \rightarrow H_2CO_3 \qquad \text{Eq. (2.1)}$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad \text{Eq. (2.2)}$$

From the previous study, the hydration product and un-hydrated cement compounds which includes calcium silicate hydrate (CSH), tricalcium silicate (C_3S) and dicalcium silicate (C_2S) can react with the atmospheric carbon dioxide. The reaction of these substances is as following (Claisse et al., 1999):

$$CSH + 3CO_2 \rightarrow 3CaCO_3 \cdot 2SiO_2 \cdot 3H_2O) \qquad \text{Eq. (2.3)}$$

$$C_3S + 3CO_2 + H_2O \rightarrow H_2O + 3CaCO_3 \qquad \text{Eq. (2.4)}$$

$$C_2S + 2CO_2 + H_2O \rightarrow SiO_2 \cdot H_2O + 2CaCO_3 \qquad \text{Eq. (2.5)}$$

2.5 CHLORIDE CORROSION

2.5.1 Causes of Concrete Chloride Corrosion

Most of the researchers had figure out several source of chloride that would attack the concrete structure. Topcu and his counterpart (2009) mention that, the chloride found in concrete come from chloride contaminated aggregates, chloride containing accelerator ($CaCl_2$), coastal environment and in direct contact with ground water. Besides, Montemor (2003)mention about the present of chloride in concrete may due to the use of chloride contaminated ingredient during manufacturing the mix or exposure of the concrete structure to marine environment. In addition, Zivica (2003) believe the chloride penetrates into concrete through sea salt spray or drying and wetting cycle of sea water.

Furthermore, micro-cracks had formed in the Portland based concrete as it is a composite material and relatively unstable. The cracks in concrete also formed due to exposure to severe environment and service loads (Sarawathy and Song, 2007). The cracks allow the transportation of chloride to take place. The pore size distribution and continuity determine the concrete permeability (Yang and Wang, 2004). The corrosion effect can be speed up by inadequate concrete cover or poor quality concrete (Kyong and Eun, 2005).

2.5.2 Mechanism of Corrosion

A thin layer of iron oxide that formed on the surface of steel reinforcement can lower the chloride corrosion rate to significantly low (Topcu and Boga, 2010). A thin layer of iron oxide, the passive film ($\square$-$Fe_2O_3.H_2O$) is built up in the high alkalinity condition of concrete. The passive film formed is very stable and not soluble (Topcu et al., 2009).

The ingression of chloride is provided by the pore solution in concrete. The passivation of steel reinforcement bar happens when the approach of chloride (Montemor et al., 2003). The break down the passive film on steel reinforcement bar, thus initiates the surface of steel to become anode and cathode will form on passive surface. The chloride also prevents re-passivation reaction to carry out and make the reinforcement steel to corrode (Topcu et al., 2009). The corrosion of steel will start as soon as the oxygen and moisture are present (Bouteiller et al., 2012). The corrosion can cause rust to form on the steel reinforcement bar.

2.5.3 Effect of Corrosion

Shorter service life of is observed on the concrete structure that built at coastal region and off shore (Kyong and Eun, 2005). The reduced in service life of structure is caused by corroded reinforcement steel (Bouteiller et al., 2012). The rust formed can make the steel reinforcement to expand 3 to 8 times larger than its original volume. This expansion can impose stress on the surrounding concrete and results in cracking and spalling of concrete cover (Topcu and Boga, 2010). As the corrosion of embedded steel continues, the products formed exert enormous stress on the concrete. These stresses have been reported to be as high as 450 MPa (Topcu et al., 2009).

Besides that, the corroded steel reinforcement will have reduced cross section of reinforcement bar and thus decreases it load carrying capacity and degrades the integrity of surrounding concrete (Jaffer and Hansson, 2009).

2.6 CONCRETE WITH ADDED POZZOLANIC MATERIAL

Researches had used kinds of pozzolanic material with high silica content in study the chloride resistance of concrete. The mineral admixtures used include silica fume, fly ash, ground granulated blast furnace ash, rice husk ash and so on. Most of the research shows positive result of the blended concrete towards corrosion.

In 2010, Topcu et al. had carried out a research of the effect of granulated blast-furnace slag on corrosion performance of steel embedded in concrete. They had conducted impressed voltage test onto normal concrete and blended concrete. Concrete with 25 % slag replacement showed longer deterioration time as compared to normal concrete. From this experiment, the blended concrete of 25 % slag replacement has higher chloride resistance as compared to normal concrete.

Besides that, Ferraro and Nanni had conducted a research onto the corrosion resistance of concrete containing rice husk ash in year 2012. The concrete samples prepared were containing 0.44 water cement ratio and three batch of concrete replaced respectively 0 %, 7.5 % and 15 % by weight of cement by rice husk. Through impressed voltage test, they found out the concrete contains 15 % rice husk ash need more than three times of duration to create first crack on concrete.

2.6.1 Palm Oil Fuel Ash (POFA)

Palm oil industry is blooming in Malaysia since last decade, and it has become one of the largest industries in this country. Malaysia is the second largest palm oil export country, which contributes 30 % of global palm oil demand (European Union delegation to Malaysia, 2012). In the processing of palm oil extraction, nut shells, pressed fibres and empty fruit brunches are produced. These unwanted materials are reused as fuel for steam generation to extract crude palm oil. The ash (POFA) produced from burning is disposed at landfill, causes traffic hazard and potential health hazard (Bamaga et al., 2010).

2.6.2 Uses of POFA in Chloride Resistance Concrete

To make good use of POFA, researches had conducted to study its performance in enhancing quality of concrete. Tay and Show (1995) had conducted an experiment by replacing Portland cement with 10 %, 20 %, 30 %, 40 %, and 50 % of palm oil bunch ash. The results form experiment shows the blended concrete had less compressive strength than normal concrete. By using 10 % of palm oil bunch ash to replace Portland cement showed acceptable result. So, they recommended the replacement ratio had to be around 10 %.

Abdul Awal and Abu Bakar (2011) also conducted a study on the properties of concrete contain high volume palm oil fuel ash. They introduced high volume of palm oil fuel ash into concrete, in which the replacement ratio was 50 %, 60 % and 70 % with different water cement ratio. They found that the high volume POFA concrete has slower strength gain at early age.

Other than that, researches on the performance of POFA in chloride resistance had also conducted. Bamaga et al. (2010) had studied on the chloride resistance of concrete containing palm oil fuel ash. They ground the POFA before added it into concrete. The POFA that they were used is reduced to 45μm in size. The ground POFA had replaced 20 % of Portland cement and the concrete was evaluated for 7, 28, 90 days of curing. From this study, they found that the ground POFA concrete showed significant improvement in properties of chloride resistance.

2.7 MECHANICAL PROPERTIES OF POFA CONCRETE

2.7.1 Compressive Strength

The compressive strength of concrete is checked to ensure its applicability in construction and knowing the strength development of the concrete. From the study conducted by Bamaga and his partners in 2010, they found that the POFA concrete shows lower early strength; might due to the lesser amount of cement powder which contribute to early strength development. As the curing age of concrete increased to 28 days and 90 days, the POFA concrete shows better compressive strength which increased up to 8.10 % as compared to plain concrete. The silicon dioxide (SiO_2) in POFA reacted with calcium hydroxide which is the product from hydration of cement to produce additional calcium silicate hydrate (C-S-H) gel (Bamaga et al., 2010).

2.7.2 Porosity

Porosity of concrete refers to the percentage of water absorption; more specifically is knowing the pore volume in harden concrete (Ferraro and Nanni, 2012). The porosity of concrete is correlated to the concrete performance. From study done by Ferraro and Nanni in 2012, it was found that the denser the concrete, the stronger of concrete in terms of compressive strength and chloride resistance. It is also found that the porosity decreases as the curing period is longer and increases the amount of pozzolanic material as partial cement replacement.

The increasing amount of POFA as partial cement replacement material decreases the porosity of concrete (Megat Joharia et al., 2012). From the study, the highest reduction of porosity has reaches 27 % for the concrete containing 60 % of POFA.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the method and detailed procedures to conduct each test is documented. This study is divided into several parts to ensure the testing is done according to standard requirement. The main work for this study is sample preparation, water curing, sample testing and data analysis. Sample preparation including checking the particle size distribution of each material to be used and chemical analysis for UPOFA was carried out before the concrete mixing is conducted. After the quality of material for sample is satisfied, the concrete casting commences. All harden concrete sample is water cured for at least 28 days. Sample testing was started after the curing age has reached. All data collected from test was presented in graphs and evaluated.

3.2 MATERIALS FOR CONCRETE SAMPLE

Ordinary Portland Cement (OPC) that fulfils the requirement of ASTM C150 (American Society for Testing and Materials, 2007) is to be used in this experiment. Fine river sand will be used as the fine aggregate and coarse aggregate should not larger than 10 mm (Megat Joharia et al., 2012). Sieve analysis has to be done on both aggregate prior add into concrete. The sieve analysis ensures the aggregates used had fulfilled the requirement of BS 882:1992 (British Standards, 1992). Ultrafine POFA will be used as partial cement replacement.

3.2.1 Ultrafine POFA Preparation

The POFA is to be obtained from the nearest palm oil mill, Felda's palm oil mill located at No. 21, Jengka. The POFA used in this experiment was come from the same batch, as to prevent the variation in chemical or physical properties. The POFA was kept in sealed container to prevent it to fly all over the place.

The raw POFA was treated before added into concrete. Firstly, the POFA was dried at 105 ± 5 °C in oven for 24 hours in order to remove moisture. The dried POFA was sieved passing 300μm sieve to remove larger particle or un-burnt shell and fibre. The sieved POFA was ground by grinding machine to reduce the particle size. The targeted median particle size, d_{50} has to be about 5μm (Givi et al., 2010). The sieved POFA was proposed to grind up to 20000 revolutions to achieve the targeted particle size. After grinding, the particle size of POFA was checked using Mastersizer Scirocco 2000 to ensure it meet the targeted particle size of ultrafine POFA (UPOFA).

3.3 CONCRETE MIX DESIGN

Normal concrete was used in this experiment. The targeted concrete strength is ranges from 25 to 30 N/mm^2. The concrete mix design is tabulated in Table 3.1. Four types of concrete mixes were produced, which is normal concrete and blended concrete with varied cement replacement by weight using 10 %, 20 % and 30 % UPOFA.

Table 3.1: Concrete mix design

Name of mix	Cement (kg/m^3)	UPOFA (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
OPC	427	0	787	961	205
UPOFA 10	385	42	787	961	205
UPOFA 20	342	85	787	961	205
UPOFA 30	299	128	787	961	205

3.4 FLOWCHART OF RESEARCH METHODOLOGY

Figure 3.1 shows the flowchart of research methodology for all testing includes sieve analysis, compressive strength test, porosity test, impressed voltage, salt ponding and half-cell test in order to investigate the effect of UPOFA on concrete chloride corrosion resistance.

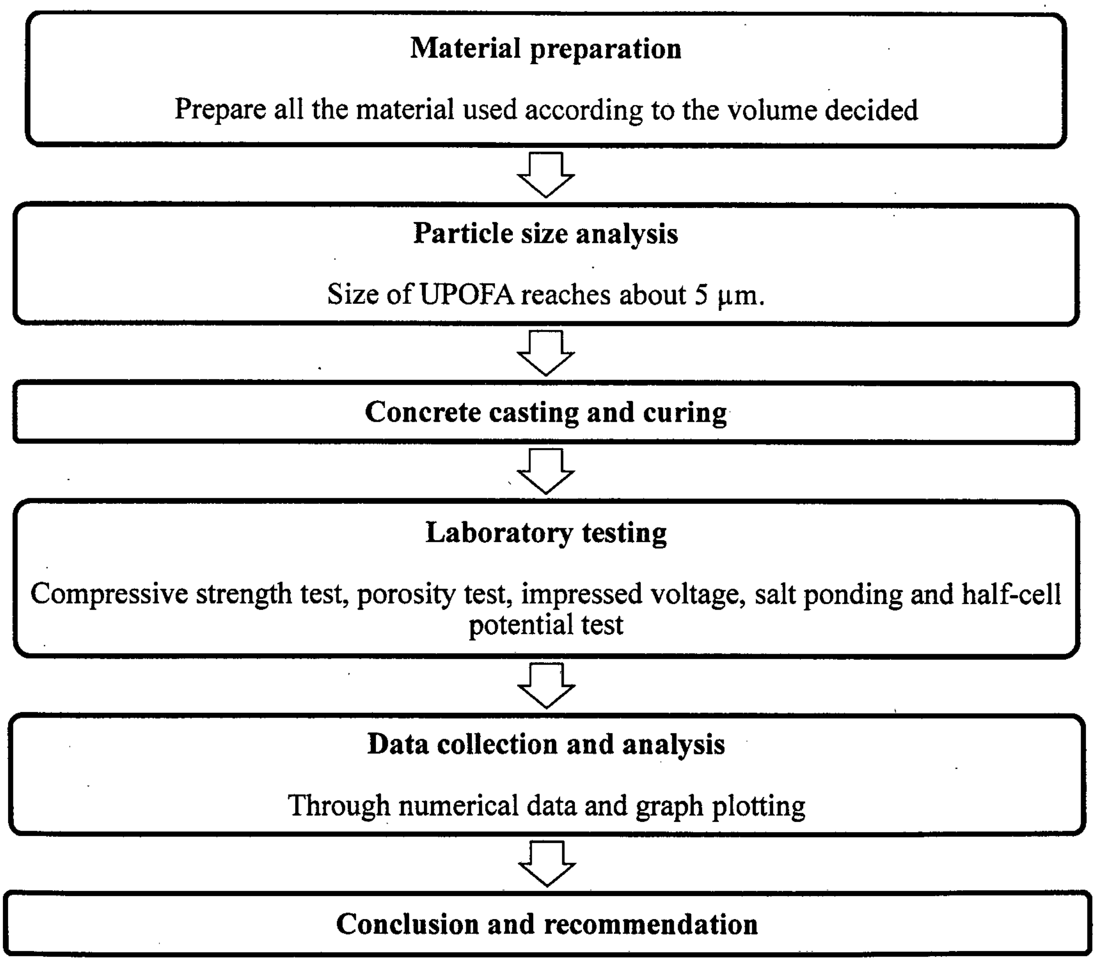

Figure 3.1: Flowchart of research methodology

3.5 CASTING CONCRETE SAMPLE

For each type of mix, two cylinders measured 100 mm in diameter and 200 mm height, one piece of slab (150 x 150 x 80 mm) and one cube (100 mm) of concrete samples were produced. Formwork was made to the designated size. The formworks was prepared and sealed with epoxy to prevent leakage during concrete compacting process.

The concrete paste was mixed using concrete mixer. The cement, fine aggregate, coarse aggregate was weighted and mixed thoroughly using concrete mixer. The amount of UPOFA added is varied for each type of mix. Water was added at the last stage, after the other ingredient was properly mixed. All formworks were placed on vibrating table to compact the concrete mechanically to minimise the air pocket and voids. The fresh concrete was poured into formworks in two layers. The fresh concrete was vibrated once the formwork was half-filled. The half-filled formwork was left to vibrate for 20 seconds. Second layer of fresh concrete paste was then added into the formworks. The vibration work started again after the fresh concrete has filled up the formworks. The vibration of fully filled formworks continued for 20 seconds. The excessive amount of concrete was wiped off using screed.

For cylinder sample, steel bar of 14 mm diameter was embedded at the centre to depth of 180 mm. The steel bar is held into place by adding supports to it.

3.6 CURING OF CONCRETE SAMPLE

The curing of samples has to begin after the concrete casted. Wet gunny bag was used to cover the sample for one day, in order to let the concrete harden and shaped in formworks. All concrete samples were moved into water pond after that. The samples were cured in water for 28 days. Testing of concrete was start after the concrete was water cured for at least 28 days.