SULPHATE RESISTANCE OF OIL PALM SHELL LIGHTWEIGHT AGGREGATE CONCRETE CONTAINING PALM OIL FUEL ASH

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ABSTRACT

The ever popular issues of environmental preservation and sustainability all over the world has led to innovations of new materials using by-products generated from various sectors. Oil palm shell (OPS) is a waste material obtained during the extraction of palm oil by crushing of the palm nut in the palm oil mills. It is one of the most abundantly produced waste materials in South Asia. While, palm oil fuel ash (POFA) is a wastage from the palm oil industry which is disposed at the landfill. In this study, the durability performance of OPS lightweight aggregate concrete containing POFA as a partial cement replacement upon sulphate attack is determined. The replacement of cement by different percentage of POFA ranges from 0% to 40%. The sulphate resistance test of OPS lightweight aggregate concrete containing POFA is conducted by preparing 100mm cubes. After the cubes were water cured for 28 days, it was placed in sodium sulphate solution which prepared according to ASTM C 1012-04 for several weeks. The influences of POFA content in OPS concrete on physical changes, mass change and strength loss were determined. The results revealed that, there is no physical changes occurred along the short period weeks of immersion. Mix produced using 20% POFA exhibit the lowest mass change value and highest residual compressive strength after exposure to sulphate solution. Use of 20% POFA has lead to densification of OPS lightweight aggregate concrete internal structure through better pozzolanic reaction that taken places. Conclusively, 20% of POFA is the best recommended amount to be used as partial cement replacement to produced OPS lightweight aggregate concrete with better durability.

ABSTRAK

Isu popular berkenaan pemuliharaan dan kelestarian alam sekitar di seluruh dunia telah membawa kepada inovasi bahan-bahan baru dengan menggunakan sisa buangan yang dikeluarkan dari pelbagai sektor. Tempurung kelapa sawit adalah bahan buangan yang diperolehi semasa pengekstrakan minyak sawit dengan menghancurkan biji sawit di kilang-kilang minyak sawit. Ia adalah salah satu daripada bahan-bahan buangan yang paling banyaknya dihasilkan di Asia Selatan. Manakala, abu terbang kelapa sawit pula adalah sisa buangan daripada industri minyak sawit yang dibuang di tapak pelupusan. Dalam kajian ini, prestasi ketahanlasakan konkrit agregat ringan tempurung kelapa sawit yang mengandungi abu terbang kelapa sawit sebagai bahan pengganti separa simen terhadap serangan sulfat telah dikenal pasti. Penggantian simen dengan peratusan abu terbang kelapa sawit adalah di antara 0% hingga 40%. Ujian rintangan sulfat konkrit agregat ringan tempurung kelapa sawit yang mengandungi abu terbang kelapa sawit dijalankan dengan menyediakan kiub bersaiz 100mm. Kiub diawet dengan kaedah rendaman air selama 28 hari sebelum direndam di dalam larutan natrium sulfat yang disediakan mengikut ASTM C 1012-04 selama beberapa minggu. Pengaruh kandungan abu terbang kelapa sawit terhadap ketahanlasakan konkrit aggregate ringan tempurung kelapa sawit dinilai berdasarkan fizikal, perubahan berat dan kehilangan kekuatan. Keputusan menunjukkan bahawa, tidak ada perubahan fizikal berlaku sepanjang minggu rendaman dijalankan kerana tempoh rendaman yang singkat. Campuran yang dihasilkan menggunakan 20% abu kelapa sawit mempamerkan nilai perubahan berat paling rendah dan kekuatan mampatan tertinggi selepas terdedah kepada serangan sulfat. Penggunaan 20% abu kelapa sawit telah meningkatkan kepadatan struktur dalaman konkrit ringan agregat tempurung kelapa sawit melalui tindakbalas pozzolana yang berlaku. Kesimpulan yang dapat dibuat daripada kajian ini ialah, 20% abu terbang kelapa sawit adalah jumlah terbaik yang disyorkan untuk digunakan sebagai bahan separa pengganti simen untuk menghasilkan konkrit agregat ringan tempurung kelapa sawit dengan ketahanlasakan yang lebih baik.

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LIST OF SYMBOLS

s	Second
%	Percent
°C	Degree Celcius
MPa	Megapascal
Kg/m3	Kilogram per cubic meter
μm	Micrometer
mm	Milimiter

LIST OF ABBREVIATION

ASTM	American Society of Testing of Materials
C_2S	Dicalcium Sulphate
C_3A	Tricalcium Sulphate
C_3S	Tricalcium Aluminate
C-S-H	Calcium Silicate Hydrate
FFB	Fresh Fruit Bunch
LWAC	Lightweight Aggregate Concrete
MPOB	Malaysia Palm Oil Board
OPC	Ordinary Portland Cement
OPS	Oil Palm Shell
POFA	Palm Oil Fuel Ash
SP	Superplasticizer
UMP	Universiti Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

In construction, concrete is the most important thing or material that has been used since a long time ago. Continuous research in area of concrete material has resulted in many types of concrete known in various names each having unique characteristics to fulfill the current construction industry demand. One of the concrete that becoming famous nowadays is lightweight aggregate concrete,(LWAC) due to its lightness, versatility and easy to handle character. LWAC is an incredibly useful and flexible building material that is composed of cement, water, sand and lightweight aggregates. Apart from all the basic constituents used to produce this concrete, other materials can also be used to replace some of these constituents. One of them is pozzolan that can be used to enhance the properties of the concrete.

The pozzolanic materials that are mostly available in Malaysia is palm oil fuel ash (POFA). POFA is generated as by-products from palm oil mills. Now, thousands of tons of ash are produced annually by an operation of 200 palm oil in mills in Malaysia and simply disposed without any commercial return (Awal and Hussin, 1997). POFA is an agro waste ash that contains a large amount of silicon dioxide and has high potential to be used as a cement replacement. In this study, POFA have be used as a pozzolanic material because it's help to improve the durability and can minimize the total cost of construction due to the less

cement used. Besides that, it will also be beneficial to the environment with respect to reducing the waste disposal volume of landfills (Tangchirapat *et al.*, 2009).

At the same time, the increasing demand of construction materials has lead towards the use of natural aggregates. Hence, the cost of construction has been arising sky high. In order to reduce the consumption of this natural aggregate and to ensure environmental sustainability, the use of alternative constituent in concrete has now been widespread all around the world. In this study, Oil Palm Shell (OPS) is used as a lightweight aggregate. In general, Malaysia currently produces more than half of the world's total output of palm oil planted over 4 million hectares of land which yield about 18.88 tonnes of fresh fruit bunch (FFB) (MPOB, 2005). The fresh fruit bunches contains about 5.5% shell (Ma *et al.*, 1999) and consequently, over 4 million tones of OPS solid waste is produced annually. Fortunately, the utilization of OPS, in concrete industry is very rewarding for both agricultural sector and concrete industry. In 2006, Teo *et al.*, stated that oil palm shells can also be used for the construction of low-cost houses.

1.2 PROBLEM STATEMENT

Palm oil is the main product in tropical climate countries and Malaysia is the top producer of it. Generally, after combustion process was completed, about 5% palm oil fuel ash by weight of solid waste is produced (Sata *et al.*, 2004). The dumping of POFA has become a massive problem to palm oil power plant because this wastage has not been recycled or reused. This problems also have been highlighted by Tay and Show (1995) who stated that this ash has also caused potential health hazard and environmental problems.

Apart from that, there is also an annual production of more than 4 tonnes of waste Oil Palm Shell (OPS) in Malaysia, (Teo *et al.*, 2006). It is a waste that creates pollution to the environment. Therefore, by using POFA and OPS as a partial replacement concrete material, the problem regarding environmental pollution can be

reduced besides decreasing the cost of construction due to the least amount of cement used.

1.3 OBJECTIVE OF STUDY

The main aim of this research is to study the durability performance of oil palm shell lightweight aggregate concrete containing palm oil fuel ash as partial cement replacement towards sulphate attack. The objectives of this study are as follows:

i. To determine the physical changes on oil palm shell lightweight aggregate concrete containing palm oil fuel ash upon sulphate attack.
ii. To determine the mass change of oil palm shell lightweight aggregate concrete containing palm oil fuel ash exposed to sulphate attack.
iii. To determine the strength loss of oil palm shell lightweight aggregate concrete containing palm oil fuel ash exposed to sulphate attack.

1.4 SCOPE OF STUDY

This study is an attempt to incorporate POFA as partial cement replacement material in lightweight aggregate concrete. Basically, this study is focused on investigating sulphate resistance of OPS lightweight aggregate containing palm oil fuel ash (POFA) as a partial cement replacement. Moreover, this study is also conducted to determine the physical changes and mass change of OPS lightweight aggregate concrete containing palm oil fuel ash upon sulphate attack. For determining the strength loss of OPS lightweight aggregate containing palm oil fuel ash upon sulphate attack, laboratory test will be conducted. The replacement of cement by the percentage of POFA in this study ranges from 0% to 40%. The total specimen used in this study was 60 cubes with a size of 100mm x 100mm x 100mm.

1.5 SIGNIFICANCE OF RESEARCH

Throughout this study, we will be able to know the durability performance of oil palm shell (OPS) lightweight aggregate concrete containing palm oil fuel ash

(POFA) as a partial cement replacement when exposed to sulphate attack. By using OPS and POFA in lightweight aggregate production, it will also be beneficial to the environment with respect to reducing the waste disposal volume of landfills. Besides that, the cost of oil palm shell lightweight aggregate concrete production also would be reduced due to the integration of POFA as a partial cement replacement that lead to the reduction in the amount of cement used.

1.6 LAYOUT OF THESIS

This thesis paper consists of five chapters. Throughout the first chapter, the discussion focuses on the introduction of the study where a brief explanation on palm oil fuel ash (POFA),oil palm shell (OPS) and lightweight aggregate concrete (LWAC) is presented. The problem statement on why POFA and OPS were used in this study is also discussed. The objectives of the study were stated in this chapter. The scope of the study and the significance of research also is revealed in this chapter. While, in chapter two, the review on oil palm shell, palm oil fuel ash and characteristics of sulphate was discussed. These include the review on materials used such as coarse aggregate, sand, cement, water and superplasticizer. The properties of OPS/POFA and LWAC concrete were also discussed in this chapter.

For chapter three, the discussion is on the methodologies used in this study. The material preparation and method on how to prepare the specimens were discussed in this chapter. The testing methods used in testing the specimens are also presented in this chapter. Chapter four mainly presents and discuss on the laboratory results of OPS lightweight aggregate concrete incorporated with POFA in terms of physical changes, mass loss and determination of strength deterioration factor upon exposure to sulphate attack.

In chapter five, the conclusion for the whole study is made. Few conclusions have been drawn with respective objectives listed based on the results obtained from this study. Besides, few recommendations are listed in this chapter for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete is well known of being the most versatile man-made building materials to be used as for its enormous advantages in terms of durability and strength of concrete. It consist a rationally mixture of cement, aggregates, sand and water. In this fast paced world, addition of waste materials in concrete has rapidly increased due to the booming of construction industry. This is parallel to the effort in reducing consumption of energy from industries due to the greenhouse effect, high energy cost and diminishing energy sources in the world.

Concrete production has certainly consumed enormous amounts of natural resources such as sand which has caused substantial environmental losses. In Malaysia alone, the abundant amount of natural silica sand is devoted to the country's glass-making and construction industry (Kwan, 2006). Therefore, it is seen that integrating palm oil fuel ash as partial cement replacement and oil palm shell as aggregate in concrete would reduce the utilization of natural resources in concrete production.

During recent decades, about thousands of tons of palm oil fuel ash (POFA) are produced yearly by operation of 200 palm oil mills in Malaysia and most of these POFA are normally disposed for landfill without any commercial returns (Awal, 1997). Ahmad *et al.* (2005) reported that, palm oil fuel ash which contain siliceous compositions and are able to react as pozzolanic materials to produce a stronger and denser concrete when it is used as partial cement replacement material.

As Malaysia has been planning in exporting palm oil as an economic restructuring to alleviate poverty and also the country focus of being a main hub for bio-technology industry in the region, it is estimated that millions tons of waste will be produced annually and the government needs to allocates landfills to dispose the waste. Success in adding POFA as partial cement replacement materials in concrete production would be able to reduced amount of waste ending at landfill.

2.2 MODIFIED CONCRETE

Modified concrete is an alteration in concrete properties in order to improvise the concrete. It is usually done by replacing part of the cement content by weight of pozzolanic materials and recent research has also replaced part of fine and coarse aggregate with pozzolanic material. Some of the examples of pozzolanic material that has been utilized in the concrete are flu ash, silica fume, palm oil fuel ash and rice husk ash. Modified concrete is used by people in producing high strength concrete because most of its mechanical and durability properties are better than those of normal strength concrete (Tangchirapat *et al.*, 2009). Also, the goal of modified concrete is to transform all concrete into a general purpose building material that is composed of eco-friendly components and produced crack-free and high durable structure (Mehta, 2004).

The benefits of modified concrete is that it can create extra strength by pozzolanic reactions, to reduce the permeability and to improve the durability of the concrete (Tangchirapat *et al.*, 2009). In addition, by reusing the waste product from industries, the source of the pollutions can be reduced, besides than helps to reduce

the cost of waste management and make our environment more sustainable (Ali *et al.*, 1996). Other benefits of using the modified concrete is that the environmental impact that can be reduced by making sustainable use of pozzolanic materials which commonly holds no value in the market.

2.3 OIL PALM SHELL

Palm oil processing is separated into six stages that are sterilization, threshing, pressing, separation of kernel and shell and clarification (Abdullah, 1996). Oil palm shell are the end product in palm oil manufacturing process. The waste produced during manufacturing process of oil palm is the shells. Its color ranges from dark grey to black. The shell consists of different shapes such as angular, polygonal and other shapes depending on the breaking pattern of the nut.

Oil palm shell is lighter than conventional coarse aggregate which will consequently result in the concrete to be lightweight. Mannan (2001) have found that, lightweight concrete using OPS as coarse aggregate is able to produce concrete with compressive strength of more than 25MPa. A footbridge constructed in Malaysia using OPS as coarse aggregate in May 2001 has been performing well even when subjected to two-wheeler traffic. Apart from that, a low cost house which is built in Sarawak in 2003 using OPS hollow blocks for walls and OPS concrete for footings, lintels and beams is also performing well and has no structural problem at all. In brief, the utilization of OPS as coarse aggregates in concrete is mainly used to reduced the depletion of natural resources due to its consumption as a construction material.

2.3.1 Definition of Oil Palm Shell

Oil palm shell is the end product of oil palm manufacturing process. Oil palm is a fruit of palm tree. The palm tree grows in a region where the temperature is very hot and rains a lot such as Malaysia and Nigeria. Oil palm fruit consist of two major parts that is pulp that is a yellow fruit and when crushed, produces palm oil and kernel

which is bounded in the shell of the seed when kernel is crushed, it produces palm kernel oil.

Oil Palm Shell (OPS) has been used as an aggregate in concrete mixture, replacing the normal sense aggregate in many countries, since long time, and it is still an important aggregate in terms of quantity used. OPS is lighter than conventional aggregate which will consequently result concrete to be lightweight. Mannan (2011) have found that lightweight concrete using OPS as coarse aggregate is able to produce concrete with compressive strength of more than 25MPa. A footbridge constructed in Malaysia using OPS as coarse aggregate in May 2001 has been performing well even when subjected to two-wheeler traffic. In brief, the utilization of OPS as a coarse aggregate in concrete is mainly used to reduce the depletion of natural resources due to its consumption as a construction materials.

2.3.2 Availability of OPS in Malaysia

Malaysia being the largest palm oil producer in the world has total planted area coverage of 3.8 million hectares and produced 4 millions tons of OPS annually (Malysia Palm Oil Board, 2005). The OPS aggregate were obtained from local oil palm mills. The species of oil palm tree normally found in Malaysia are oleifera, dura, psifera, and tenera. Except for psifera species (which has virtually no shell to the kernel), the shell comprises approximately 10% to 50% of the total composition of the oil palm fruitlets. OPS is available in various shapes, such as curved, flaky, elongated, roughly parabolic, and other irregular shapes.

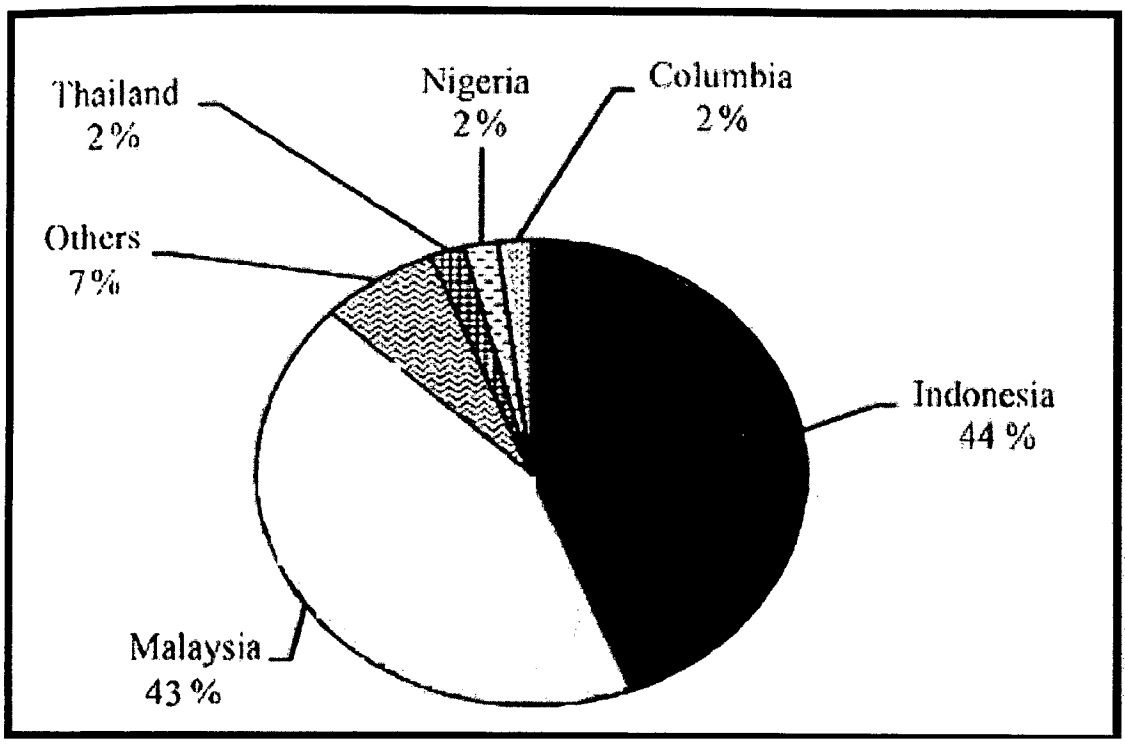

Figure 2.1 : World producer of oil palm in 2006

Sources :Shuit, *et.al.*, (2009)

Malaysia is one of the world leaders in the production and export of palm oil (Subramaniam *et al.,* 2008). According to this statement, OPS is easily being found in Malaysia because it is contributes about 57.6% of the total supply of palm oil in the world. This industry is one of the main pillars of the country's economy contributing some RM 28.60 billion in export earnings from palm oil and oil palm products in 2006 (MPOB, 2006). However, the large amount of OPS produced have caused the nation environmental and storage problem due the dumping of a large amount of oil palm shell.

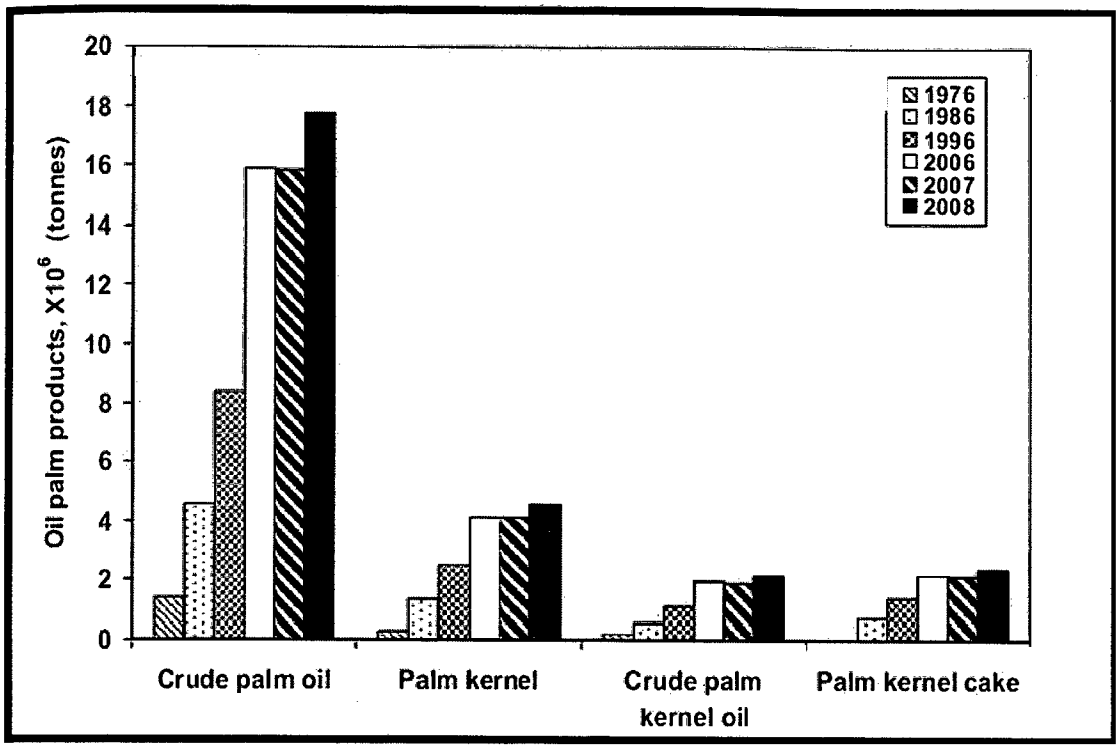

Figure 2.2 : Production of palm oil products from 1976 to 2006, 2007 and 2008

Sources: Sulaiman *et al.*, (2011)

2.3.3 Oil Palm Shell Properties

According to Abdullah (1996), the process of palm oil is separated into six stages; sterilization, threshing, pressing, depericarping, separation of kernel and shell and clarification. During the process, shells are one of the wastes that is produced. The color of the shells varies, from black to dark grey. There are different types of shells which includes angular and polygonal. Talking about the surfaces of the shells, they are quite smooth for convex and concave. One the other hand, the broken edge is thorny and uneven. As stated by Basri *et al.* (1999) and Okpala (1990), the thickness is different too. It is highly depending on the species of the palm tree from which the palm nut is obtained. The ranges are from 0.15 to 8 mm.

2.4 PALM OIL FUEL ASH (POFA)

2.4.1 Definition 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 waste is produced (Sata *et al*, 2004). Malaysia is one of the world's leading producers and exporter of palm oil and palm oil products. The oil palm was first introduced in Malaysia in 1870 as an ornamental plant. There are more than two hundred palm oil mill plants operating in the country. Either in 20^{th} or 21^{st} century, POFA is still considered as a nuisance to the environment and is disposed without being put for any other use as compared to other types of palm oil by-product.

It has been found that the properly process POFA can be used successfully as a supplementary cementing material for producing various type of concrete. The use of POFA in concrete contributes to enhance the quality of concrete with respect to strength and durability due to its micro-filling ability and pozzolanic property (Tangchirapat *et al.,* 2007). In the pozzolanic reaction, the SiO_2 and Al_2O_3 contents of POFA involve in the reaction with $Ca(OH)_2$ to form C-S-H and calcium aluminate hydrate (C-A-H). The Al_2O_3. SiO_2 framework can also be formed from pozzolanic reaction. However, the main reaction product of pozzolanic reaction is C-S-H gel that enhances the strength of cement paste as well as improve the microstructure of concrete (Salam *et al.*, 2013)

2.4.2 POFA in Malaysia

To date, thousands of tons of ash are produced annually and are simply disposed in landfills. Sumadi and Husin (1995) have found that the POFA produced in Malaysian Palm oil mill is dumped as waste without any profitable return as it is

considered worthless. Since Malaysia continuos to increase the production of palm oil, therefore more ashes will be produced and failure to fine any solution in making use of this by-product will create severe environmental problems. Chindaprasirt *et al.,* (2007) stated that the increasing amount of palm oil fuel ash disposed in landfills has now become a burden and nuisance to the environment. There will be approximately 20 tonnes of nut shells, 7 tonnes of fibers, and 25 tonnes of empty bunches discharged from the mill for every 100 tonnes of fresh fruit bunches processed (Tay, 1995).

2.4.3 Palm Oil Fuel Ash Characteristics

POFA is a pozzolanic materials as indicated by both physical properties and chemical analysis (Sumadi and Hussin, 1993; Awal and Hussin, 1997). This characteristic is crucial in determining the suitability of using POFA as a partial cement replacement in concrete. The physical properties of POFA are greatly influenced by the burning condition, particularly burning temperature (Abdullah *et al.,* 2006). In particular, the rate of hydration, pozzolanic reaction and development of POFA concrete strength depends on the fineness of particles. From the scanning electron microscopy, it is found that underground POFA particles are mostly large, spherical and porous. In contrast, the ground POFA generally consist of smaller crushed particles with irregular and angular shape similar to the Portland cement (Chindaprasirt *et al.*, 2007). This shows that the ground POFA is coarser than OPC but the ground POFA becomes finer than OPC.

Usually, the particles size of POFA can be reduced by the grinding process in ball mills or Los Angeles abrasion machine using mild steel bar instead of steel ball (Abdullah *et al.*, 2006). The grinding process reduces not only the particles size but also the porosity of the POFA (Kiattikomol *et al.,* 2001). After grinding, POFA can be less porous with smaller particles (Paya *et al.,* 1996). The general physical properties of raw and ground POFA are presented in Table 2.1.

Table 2.1 : Physical characteristics of as received and the blended ground POFA

Physical Properties	Raw POFA	Ground POFA
Appearance before ignition	Dark spongy	Grayish, powdery
Appearance after ignition	Porous, grayish	Brownish
Texture	Hard; gritty, light, cellular	Powdery
Shape	Irregular	round

Source : Oyeleke *et al.,* (2011)

2.4.4 Utilization of POFA in Concrete

There are many uses of POFA in concrete production especially towards improving the properties of concrete. According to (Tay and Show, 1995), they had revealed that the compressive strength of concrete decreases as the POFA content increases. In contrary, other researcher have found that the concrete made with POFA exhibit a higher compressive strength than OPC concrete (Tonnayopas *et al.,* 2006).

As a master of fact, Chindaprasirt *et al.* (2006) have stated that the POFA can be applied as the new pozzolanic materials in concrete with an acceptable strength. They added that the optimum cement replacement by POFA is 20% which if it is beyond this ratio, the compressive strength is reduced and also tends to give higher permeability of concrete. Nevertheless, it was suggested to use finer POFA in order to achieve better strength of POFA concrete (Hussin and Awal, 1996). Consequently when using the unground POFA, the reduction in the strength of concrete is expected as it has lower particles surface area that affects the pozzolanic activity in the POFA concrete.

Awal and Hussin (1996) highlighted that adding POFA would enable concrete to increase the resistance of concrete towards sulphate and acid attack. The expansion of concrete due to sulphate attack decreased with the increased content of unground POFA (Jaturapitakkul *et al.,* 2007). However, high strength concrete containing ground POFA showed a better resistance to sulfate attack than normal POFA concrete (Tangchirapat *et al.,* 2009) which thereby indicates that the POFA fineness influences the sulfate resistance of concrete.

2.5 LIGHTWEIGHT AGGREGATE CONCRETE (LWAC)

2.5.1 Definition of Lightweight Aggregate Concrete

Lightweight aggregate concrete are commonly used in the construction industry where weight savings is an important factor. One of the most common used for LWAC is with floor, roof or bridge decks and others. Lightweight aggregate concrete is made by replacing some or all of the normal weight aggregate with lightweight concrete. Structural lightweight aggregate concrete is defined as concrete which is made with lightweight aggregate conforming to ASTM C 330 (Jeffrey *et al.*, 2006). They function as active pozzolanic materials when used as fine aggregates. High performance of lightweight concrete are typically made using expanded clay, shale or slate.

Lightweight aggregate can be divided into two categories. First, it is those occurring naturally and are ready to use only with mechanical treatment such as crushing and sieving. Second is those produced by thermal treatment from either naturally occurring materials or from industrial by-products, waste materials, etc. the industrial by-products are pulverized fly ash, blast furnace slag, industrial waste, sludge, etc. These are produced either by expansion or agglomeration. The heat treatment is carried out in different types of industrial furnaces, such as rotary kilns.