OIL PALM SHELL LIGHTWEIGHT AGGREGATE CONCRETE FOR ENGINEERING PERFORMANCE

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OIL PALM SHELL LIGHTWEIGHT AGGREGATE CONCRETE FOR ENGINEERING PERFORMANCE

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

OPS	Oil Palm Shell
OPSLC	Oil Palm Shell Lightweight Concrete
LAC	Lightweight Aggregate Concrete
UPV	Ultrasonic Pulse Velocity
RILEM	International Union of Laboratories and Expert in Construction Materials, System and Structure
V_f	Volume Fraction
BS	British Standard
ASTM	American Standard
NWC	Normal weight concrete
SP	Superplasticizer
OPSFC	Oil palm shell foam concrete
LWAFC	lightweight aggregate concrete foam concrete
LWA	lightweight aggregate

LIST OF PUBLICATION

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PRESTASI KEJURUTERAAN KONKRIT AGREGAT RINGAN TEMPURUNG KELAPA SAWIT

ABSTRAK

Konkrit agregat ringan tempurung kelapa sawit (OPSLC) adalah konkrit agregat ringan yang menggunakan tempurung kelapa sawit (OPS) sebagai agregat kasar. Tempurung kelapa sawit yang terhasil daripada industri pemprosesan kelapa sawit, adalah salah satu bahan buangan dan mempunyai kemampuan sebagai bahan dalam konkrit. Aplikasi utama OPSLC adalah sebagai konkrit ringan struktur dalam komponen bangunan. Kajian ini akan menerokai potensi penggunaan OPSLC sebagai konkrit penebatan dengan keupayaan untuk menanggung beban untuk panel dinding luaran dalam pembinaan terutamanya untuk rumah domestik. Kajian dan analisis telah dijalankan untuk menghasilkan dinding dengan keupayaan menanggung beban yang diperbuat daripada OPSLC. Untuk memenuhi keperluan sebagai konkrit ringan penebatan, sebanyak 15 reka bentuk campuran percubaan dihasilkan untuk meneliti ciri-ciri OPSLC sebagai konkrit penebatan dengan keupayaan untuk menanggung beban. Kemudian, tiga campuran optimum (OPS: pecahan isi padu kandungan sebanyak 30%, 32% dan 34%) yang memenuhi kedua-dua aspek tersebut dipilih dan digabungkan dengan tiga jenis bentuk OPS. Oleh itu, sebanyak sembilan campuran konkrit dinilai daripada segi sifat-sifat kejuruteraan, ketahanan dan terma pada tempoh pendedahan jangka masa panjang dengan tiga persekitaran pengawetan. Berdasarkan permerhatian selama satu tahun, OPSLC didapati mempunyai keupayaan sebagai dinding luaran yang berupaya menahan beban untuk rumah teres. Sebagai bukti, tiga prototaip dinding panel OPSLC

dihasilkan berdasarkan kajian analisis terhadap semua reka bentuk campuran. Kemudian, prototaip panel dinding OPSLC diuji dengan bebanan mampatan untuk mengetahui prestasi strukturnya. Untuk menilai kemampuan OPSLC pada suhu tinggi, satu prototaip panel dinding OPSLC dipilih untuk menjalani ujian kerintangan api selama 2 jam. Hasil kajian yang diperolehi menunjukkan bahawa prestasi penebatan terma OPSLC adalah lebih baik berbanding bahan binaan bangunan konvensional. Bahagian permukaan dinding yang tidak terdedah merekodkan bacaaan suhu hanya sebanyak 63°C selepas didedahkan kepada api selama 2 jam. Nilai tersebut adalah amat rendah berbanding suhu yang dicatatkan oleh bahan binaan konvensional. Hasil kajian berkenaan prestasi struktur OPSLC sebagai panel dinding luaran menunjukkan bahawa panel tersebut mempunyai keupayaan untuk menanggung beban yang mencukupi bagi rumah teres dua tingkat.

OIL PALM SHELL LIGHTWEIGHT AGGREGATE CONCRETE FOR ENGINEERING PERFORMANCE

ABSTRACT

Oil palm shell lightweight concrete (OPSLC) is a lightweight aggregate concrete that used oil palm shell (OPS) as coarse aggregate. Produced from the oil palm industry, OPS is one of the solid waste material and has the capability to be used as concrete material. The application of OPSLC is primarily as a structural lightweight concrete in building components. This research explores the potential of using OPSLC as insulation concrete with load bearing strength for external wall panel in construction especially for domestic houses. Experimental and analytical studies were conducted to develop OPSLC load bearing wall with insulation concrete capacity. In order to achieve the insulation lightweight concrete requirement, 15 trial mix designs were developed to examine the characteristic of OPSLC as insulation lightweight concrete with load bearing strength. Then, three optimum designs (OPS: volume fraction of 30%, 32% and 34%) that achieved both requirements were selected and incorporated with OPS of three different shapes. Thus, nine mix designs were examined in terms of engineering, durability and thermal properties in long term exposure to three different curing series environments. Based on the observation for one year performance, OPSLC is found to have the capability as external load bearing wall in domestic terrace houses. To confirm this, three prototypes of OPSLC wall panel were made based on analytical assessment study of the all mix designs. Then, the OPSLC wall panel prototypes were tested on compression load to investigate the

structural performance. To evaluate the OPSLC performance at elevated temperature, an OPSLC wall panel prototype was selected for a two-hour fire resistance test. The result indicates that OPSLC has greater thermal insulation performance compared to conventional building materials. The unexposed wall surface only recorded a temperature of 63°C after exposure to fire for two hours. The value is extremely lower than those of conventional building materials. The result on structural performance of OPSLC for external wall panel indicates that the panel has sufficient load carrying capacity to be used in two-storey terrace houses.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This study aims to explore the potential of oil palm shell lightweight concrete (OPSLC) in insulation concrete with load bearing strength capacity. The basic elements of the study are presented in this chapter, including the background, problem statement, aim and objective, and scope of study. The outline of this dissertation is summarized at the end of this chapter.

1.2 Background of Study

Oil palm shell (OPS) is solid waste material resulting from the processing of oil palm and contributes 5.5% to the overall solid waste of oil palm manufacturing process (Abdullah *et al.*, 2011). Thus, using OPS as an aggregate can be considered as ecologically desirable in order to fully utilize waste materials occurring as by-products from other industries (Pankhurst, 1993). OPS has been traditionally used as solid fuels for steam boiler to run turbines for electricity (Shafigh *et al*., 2011a) and to cover the surface of the roads in the plantation area (Abdullah et al., 2011). It was also densified into briquettes (Husain *et al.*, 2002), convert to bio-oil through pyrolysis process for biomass energy (Sahu *et al*., 2011) and used in the production of charcoal and activated carbon. For more than 20 years, researchers have investigated the potential of OPS as structural lightweight aggregate.

Through continuous research in the development of OPSLC, especially for structural lightweight concrete, results have shown improved strength of mechanical properties (Alengaram U.J *et al.*, 2013). To show the potential of OPSLC, Universiti Malaysia Sabah (UMS) has already built a mock-up house with a floor area of about 59 m^2 and a small footbridge of about 2 m in span inside the campus in 2006. Another natural advantage of the OPS is its high porosity content which then produced low thermal conductivity aggregate, similar to other lightweight aggregate such as pumice, expanded vermiculite, expanded slate and expanded clay. Thus, it is suitable to be used as coarse aggregate in lightweight aggregate concrete for thermal insulation material in building construction. Previous studies have found that lightweight aggregate can be good thermal insulation in lightweight concrete (Demirboga R. and Gul. R., 2003; A. Al-Sahby and Edward R., 2012). The fineness of the pores produces better insulation properties and also another important thing is moisture content (increase of moisture by mass linearly will increase thermal conductivity about 42%) (Narayan and Ramamuthu, 2000). Due to highly absorptive and free-flowing nature of OPS, it ideally supported the low thermal conductivity material.

Due to that condition, this study will investigate three variables to prove the potential of OPS as thermal insulation materials. First is the volume fraction of OPS, in order to determine the right amount of OPS in mix design to achieve the thermal conductivity range for insulation concrete category. Second, the shape of OPS for mechanical performance on different sizes of coarse aggregate; and third, several curing regime to evaluate the durability performance of OPSLC for long-term exposure.

To determine the capability of OPSLC as part of building element, experiments are performed to observe the compressive structural behaviour based on wall panel sample. Then, the durability at elevated temperature will also be investigated especially through fire resistance test to support OPSLC as insulation building materials and to find out the possibility of OPSLC as external load bearing wall for domestic houses.

1.3 Problem Statement

Building construction in general has been in the limelight mainly due to load carrying capacity (dead load) which are important in design stages. Lightweight concrete is commonly used to solve this matter. When using lightweight aggregate concrete, a designer will expect two main advantages: reduced dead load weigh and high thermal insulation which are significant to minimize earthquake impact. Architectural expression of form combined with functional design can be achieved easier in lightweight concrete than in any other medium (Mannan *et al*., 2006). Nowadays, architects, contractors and engineers have recognized the inherent economics and concomitant advantages offered by lightweight concrete. However, the different characteristics of lightweight aggregate and concrete required departures from customary practise to suit the purpose of design (D.C.L Teo *et al*., 2007). For example, lightweight aggregate concrete can be used as part of a building structure such as slab, wall and column.

In lightweight aggregate concrete production, the utilization and recycling of solid waste material for lightweight concrete especially from agriculture industry are very worthwhile (Shafigh *et al*., 2012). Material healing from the exchange of agricultural wastes and industrial wastes into useful materials has not only environmental gains, but may also conserve the natural resources. Some of agro waste materials have good potential or benefit to be generated back to valuable material, thus decreasing solid waste problem rather than reduction of waste production. Mannan (2007) has reported Malaysia's production of over 4 million tonnes of OPS annually as waste solid in palm oil industry. With the physical characteristic of OPS, it can be utilized as lightweight aggregate in concrete production. Usage of these of lightweight aggregate will not only provide a significant saving in the overall cost of contraction but also, by reducing solid waste it will address the concomitant environmental problem.

To realise the potential of OPS in lightweight aggregate concrete application, Harimi et al. (2006), who has evaluated the daily normal temperature of house wall surface by using OPSLC as building material, reported that OPS concrete walls temperature was always lower than the outdoor temperature. However, the study only evaluated the interior surface temperature of the wall and focused on the architectural aspect. Therefore, the effectiveness of OPS as low thermal conductivity aggregate must be explored. Thermal conductivity is the property of a material that plays a key role in all heat transfer calculations (Demirboga. R and A. Kan, 2012), may it be in the context of energy efficient building design or calculation of temperature profile. The energy performance of a building highly depends on the thermal conductivity of the building materials which describes the ability of heat to flow across the material in the presence of a differential temperature. Thus, the use of low thermal conductivity building materials is crucial to reduce heat gain through the envelope into the building in hot climate country (Ng S.-C and Low K.-S., 2011).

Although OPS lightweight aggregate concrete has been successfully produced in the past, most of the researchers focused on structural lightweight concrete purpose and the highest 28-day compressive strength of about 48 MPa (Shafigh *et al*, 2011a). Previous studies have used only around 15% to 18% OPS of volume fraction from total volume of OPSLC to produce high compressive strength. In terms of shape, crushed OPS produced better mechanical strength compared to raw OPS. However, crushed OPS will reduce the porosity content of OPS, which is an important element for insulation purposes. For structural performance, OPSLC beam was already established by Alenggaram *et al*., (2010a).

Based on previous evidences which stated that OPS have low thermal conductivity, as reported by Okpala (1990), the thermal conductivity for OPS itself is 0.19 W/m°C and for OPSLC, it is 0.45 W/m°C with ratio 1:1:2 (cement:sand:OPS), 0.5 w/c (28 day compressive strength 22 N/mm^2). However, the study only focused with 1 mix proportion to obtain the thermal conductivity. Currently, there is no study being conducted yet which fully focus on thermal properties for insulation properties of OPSLC and elevated temperature conditions especially in fire resistance capacity. Thus, this study aims to fill the gap.

Specifically in lightweight aggregate concrete for thermal insulation, moderate strength concrete have lower thermal conductivity than structural concrete. To produce moderate strength concrete, cement content used is lower than structural concrete. Thus, thermal conductivity of concrete decreases with decreasing cement content and thermal conductivity of aggregate (R. Demirboga & R. Gul, 2003).

In particular, aggregate proportion plays a legible role for effectiveness of insulating properties. Recent research by Z. Xing et al. (2011) revealed that aggregate represents a considerable proportion of volume in the concrete and the thermal conductivity of concrete must be considerably influenced by the thermal conductivity of aggregates, also according to their mineralogical composition and their internal microstructure. These views are consistent with those of O. Unal *et al.*, (2007) that aggregate generally constitutes large volume fraction in concrete and it exerts a major influence on properties of concrete.

Recently, Alengaram. U.J *et al.* (2013a) found that the addition of foam on OPS concrete will reduce thermal conductivity compared to conventional materials. However, the addition of foam tends to reduce the mechanical properties of concrete. On the other hand, hardened OPSLC (without foam) which has better mechanical strength properties can be used as thermal insulation concrete with load bearing strength. Thus, there are more to be explored in terms of engineering and durability properties of OPSLC as thermal insulation concrete material with load bearing capacity and this study will attempt to explore the possibility of OPSLC to be used as external load bearing wall with insulation concrete capacity in wall panel application.

1.4 Research Aim and Objective

The aim of this study is to assess the OPSLC in detail, based on its strength, durability and thermal properties for thermal insulation purpose. In the literature review, it is established that lightweight aggregate concrete can generally be used as thermal insulation building material and the potential of oil palm shell (OPS) to produce lightweight aggregate concrete with low thermal conductivity are also proven. Therefore, in this particular context, further research and practical test in laboratories are necessary to obtain OPSLC with insulation concrete density range and low thermal conductivity to fulfil thermal insulation requirement. The quality of the materials would also need to be ensured from the selection stage until the mix design stage.

The objectives of this research are:

1. To investigate the engineering performance of OPSLC with insulation concrete capacity
2. To assess the durability and thermal performance of OPSLC
3. To experimentally investigate the structural behaviour of OPSLC wall panel on compression load.
4. To find out the possibility of using OPSLC in fire-resistant (elevated temperature) and load bearing (structural performance) wall panel in domestic residential houses.

Our aim is to design and determine a mix design of strong and durable OPSLC with low thermal conductivity and establish OPS amount and sizes (shape) for thermal insulation purposes. Besides that, a mix design of lightweight aggregate concrete will be defined and tested in selected density of 1650 kg/m³ until 1810 kg/m³.

This study is an attempt to find any method that can work towards improvement of building materials. It focuses on the properties and the performance of the stabilized lightweight aggregate concrete. One of the targets is to propose and summarize the information, pertaining to the basic characteristics attributable to lightweight aggregate concrete and on the stabilization and low thermal conductivity.

1.5 Research Question & Hypothesis

To achieve the research objectives, the hypothesis and the research questions are as below:

The hypothesis of the study, H_1;-

Increasing OPS volume fraction in OPSLC will increase the insulation capacity due to decrease of thermal conductivity. And smaller OPS will produce higher mechanical strength due to decrease of OPS convex surface.

The study aims to answer the following questions:

i. What are the significant effects of engineering, durability and thermal properties of OPSLC with long term exposure to different curing environments?

ii. How is the structural performance of OPSLC wall panel and durability on elevated temperature?

iii. What is the possibility of using OPSLC as external load bearing wall for domestic houses?

1.6 Scope and Limitation of the Study

The scope of this research is developing OPSLC to be used in thermal insulation concrete by using OPS as main coarse aggregate. The main scopes of the research work are given as follows:

i. Assessment of the physical and thermal properties OPS as coarse aggregate.

ii. The effects of different shapes and volume fractions of OPS with different curing regimes for one year exposure (room environment, tropical climate and full water).

iii. The effects of various volume fractions and OPS shape on engineering properties of OPSLC.

iv. The effects of various volume fractions and OPS shape on durability properties of OPSLC.

v. The effects of various volume fraction and OPS shape on thermal properties of OPSLC.

vi. OPSLC structural performance in load bearing wall panel.

vii. The durability of OPSLC on elevated temperature and in wall panel (fire resistance test).

By using trial mix in the insulation concrete range, the investigation is designed to explore the engineering, durability and thermal properties of OPSLC that was exposed to full water, room environment and tropical climate up to 12 months.

The assessment on engineering properties of the OPSLC included investigations on bulk density, compressive and flexural strength, ultrasonic pulse velocity, static modulus elasticity and dynamic modulus elasticity.

The study on the durability properties includes the determination of water absorption, intrinsic permeability, porosity and scanning microscopy examination. The evaluation of thermal properties covers the thermal conductivity, specific heat and thermal diffusivity.

The investigation on structural behaviour was carried out through reinforcement wall panel (125 x 500 x 500 mm) compression load test. The monitoring parameters include the ultimate load, cracks behaviour, first crack load and buckling.

To evaluate the elevated temperature performance, especially on fire resistance test, the reinforcement wall panel (125 x 1500 x 1500 mm) was tested (2 hours exposure to fire). Important parameters such as unexposed surface temperature data, temperature transformation and integrity performance are taken. Additionally, the compressive strength and microstructure characteristics at elevated temperature were also examined.

The limitations of work are discussed as below:

i. Volume fractions of OPS are 30%, 32% and 34% only for mix design. Although higher volume fraction of OPS will produce higher thermal conductivity, the compressive strengths are below the load bearing requirement.

ii. All OPS shapes follow BS EN 882:1994 for coarse aggregate obtained from processing of natural materials.

iii. Curing environments are simulated for external wall application, which include exposure to tropical climate (air) and room condition, with water curing as the control. The exposure is until one year to examine the long term curing environment effect.

1.7 Significance of the Research Study

The present study investigates the mechanical and physical properties of OPS aggregate, and mechanical, durability and thermal characteristics of OPSLC in order to justify implementation of OPS as coarse aggregate with low thermal conductivity in lightweight aggregate concrete. Several major benefits can be derived with the successful incorporation of OPS as coarse aggregate in lightweight concrete. The most important thing in design stages is lightweight aggregate concrete will reduce “dead load” and reinforcement load thus minimizing earthquake impact. Another advantages are such as foundation cost, transport cost, saving on formwork and scaffolding, better thermal insulation and sound absorption than ordinary concrete, lower tendency to warp or buckle due to different temperature gradients, superior anti condensation properties, better fire resistance, durability, heat isolation and frost resistance. With all benefits of lightweight aggregate concrete, it will make a significant material in building construction.

Furthermore, the recycling or utilisation of solid wastes generated from most agro-based industries such as OPS is very rewarding. The concern about enormous waste production, resource preservation, and material cost has focused the attention for the reuse of solid waste. Material recovery from the conversion of agricultural wastes and industrial wastes into useful materials has not only environmental gains, but may also preserve natural resources. Thus, indirectly, this study will contribute on sustainability building material and green concept implementations.

The research also explore the possibility to extend the use of OPS as coarse aggregate to enhance the mechanical strength, durability performance and heat transfer analysis (thermal properties) on insulation concrete capacity. Thus, the study emphasized OPSLC as insulation concrete with load bearing strength.

This study found that by using volume fraction of OPS of more than 30% from total concrete volume, it will produce OPSLC insulation lightweight concrete, compared to previous studies that used OPS volume fraction of only 15% to 18% for structural concrete. With the right proportion, OPSLC would be able to achieve load bearing strength of insulation concrete capacity. It will then benefit the industrialised building system (IBS) for its potential to be used as precast wall or interlocking block application.

Experimental data on the mechanical behaviour derived from the laboratory testing of OPSLC wall panel will contribute towards a better understanding on the load deflection response, load compressive strength behaviour, ultimate load capacity, failure mode and buckling development of the wall panel upon being subjected to compressive load. These data can be used to predict the mechanical behaviour of wall panel system which is useful for load bearing wall and compression control application. Additionally, the durability performance at elevated temperature is investigated to support the OPSLC capability as insulation concrete material. The optimum design will be tested for fire resistance performance in 2 hours exposure to fire. It is important to ensure that the requirement of Uniform Building By-laws (UBBL) is complied.

Fire resistance is a major safety requirement for a domestic building. To ensure that the material achieved the standard for fire resistance, the performance of material at ambient and elevated temperature need to be tested. The findings of this study on the experimental data of the thermal properties will contribute towards a better understanding about actual potential of OPSLC in thermal insulation purpose application with fire resistance capacity especially in application for building wall.

1.8 Structure of Thesis.

This thesis consists of nine chapters to cover major aspects of the engineering, durability and thermal properties of OPS LWC, structural performance and fire resistance of reinforcement wall panel.

i. Chapter one provides general information of the study.

ii. Chapter two presents related literature review on the use of OPS as coarse aggregate in LWC including its structural performance, design and applications. Usage of lightweight aggregate for thermal insulation concrete and durability to fire resistance are also discussed. Additionally, explanations about the gap in current studies are also included to show the novelty of this research.

iii. Chapter three provides the detail of experiments conducted and relevant test methodology used during the study. The development and formulation of mix design by trial approach are also explained.

iv. Chapter four discusses the engineering properties of OPS LWC with load bearing capacity. The findings are used to support justifications for structural performance in this study.

v. Chapter five displays the experimental result of OPS LWC durability after a long term exposure to three different curing regimes. Discussions are based on published facts and cross checking with major parameters.

vi. Chapter six presents the thermal properties of OPS LWC. Important parameters such as thermal conductivity, specific heat and thermal diffusivity are analysed in this chapter to comply with insulation concrete requirement.

vii. Chapter seven exhibits the results of experiments and analyses results of the structural performance of an OPS reinforcement wall panel. The fire resistance, compressive strength and microstructure analysis in elevated temperature are also discussed in this chapter.

viii. Chapter eight summarizes the main findings and recommendations for implementation. Further researches are also suggested in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is a comprehensive review about previous studies on OPSLC. First, the usage of OPS as lightweight aggregate on coarse aggregate is elaborated. Then, the criterion concerning the development of OPSLC is further discussed before highlighting the characteristics of OPSLC. Next is the explanation on effects of OPSLC in terms of mechanical, durability and thermal properties. Detail on time-dependent properties and structural behaviour are also explained. The discussions then continue on the gap of previous studies on OPSLC.

In order to achieve the objectives of this study, related studies on lightweight aggregate concrete performance on insulation purpose are also explained and the design for insulation concrete is explored. Some information about lightweight aggregate concrete as thermal insulation concrete with several established lightweight aggregate with low thermal conductivity, and other parameter that are important in thermal properties, such as specific heat are also described. Other than that, the mechanical and durability of other lightweight aggregate in insulation range are also explained. The performance of lightweight concrete at elevated temperature in terms of fire resistance, microstructure behaviour and mechanical strength are also covered in this chapter. Finally, the last part highlighted the application of insulation concrete in building structure element.

2.2 Lightweight Concrete

Lightweight concrete can be divided into three main groups, no fine concrete, lightweight aggregate concrete and aerated concrete (Short and Kiniburgh,1978). The general term lightweight concrete refer to any concrete produced to an oven dry density of less than 2000 kg/m³ (ENV,1992) ,between 1400-1800 kg/m³ (Neville and Brooks, 2008) and not more than 1600 kg/m³ (Short and kinniburgh,1978) . The prevalent way to achieving lightweight concrete production in by using lightweight aggregate. Lightweight concrete aggregate can be separate with three types following air –dry unit weight range in 28 days (Figure 2.1)(ACI Committee 213,1990).

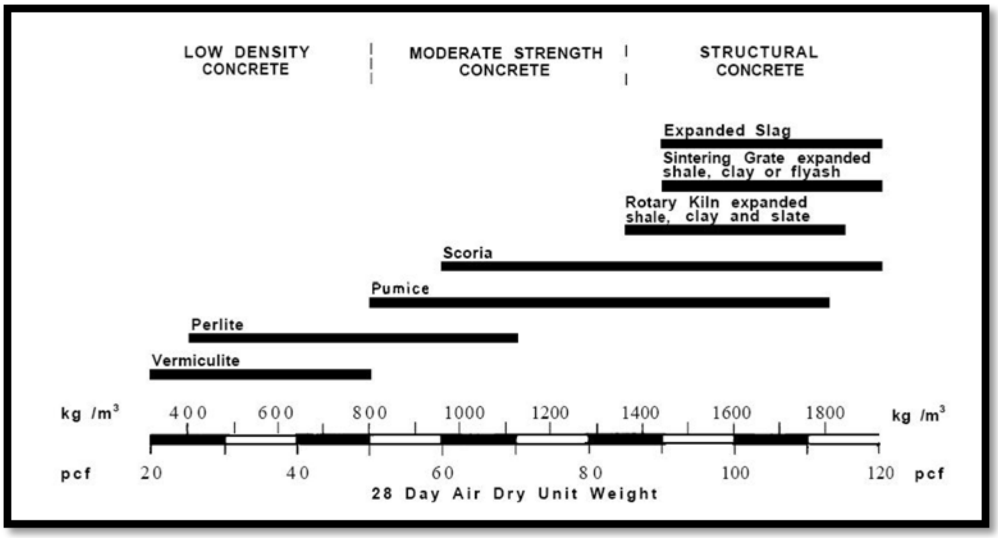

Figure 2.1: Approximate unit weight and use classification of lightweight aggregate concrete. *(*ACI Committe 213, 1990).

In the 1960s and 1970s ,lightweight aggregate concrete was used in various structure, frequently with lightweight aggregate fines. Thus the use of lightweight concrete become confined to specialist structure, such as stadia, bridge and other major works where site mixing was viable, or to structure with high dead to live load ratios where the high cost was offset by the very substantial advantages of the weight saving. (Pankhurst,1993)

Lightweight aggregate can be subdivided into two type of aggregate, natural and those manufactured (shafiqh, 2010). Natural aggregate such as volcanic tuffs, pumice (Yeginobali *et al*,1998), diatomite, scoria and volcanic cinders, for manufactured aggregate can be divided into four type. The first type produced by the application of heat in order to expand clay, shale, slate diatomaceous shale, perlite , obsidian and vermiculite Second type is obtained by special cooling processes through which an expansion of blast –furnace slag is obtained. For the third and fourth are from industrial cinder form (Neville and Brooks,2008).

Lightweight concrete is produced by including large quantities od the air in the aggregate, in the matrix, or in between the aggregate particle, or by a combination of these processes. According to the method used, the various forms of lightweight concrete can be classified as follows.

Table 2.1: Lightweight concrete classification

Type of lightweight concrete	Method of manufacture
Air entrained in between aggregate particle	• No fines concrete made with dense aggregate. • Partially compacted concrete made with dense aggregate
Air contained in between and within aggregate particle	• No – fines concrete made with lightweight aggregate • Particle compacted concrete made with lightweight aggregate
Air contained within the aggregate particle	• Fully compacted concrete made with lightweight aggregate

Aggregate that weight less than about 1000 kg/m³ are generally consider lightweight and find application in the production of various types of lightweight concrete. The light weight id due to the cellular or highly porous microstructure. However, cellular organic material such as wood chip cannot be used as aggregate because lack of durability in the moist alkaline environment in Portland cement concrete.

Natural lightweight aggregate are made by processing igneous volcanic such as pumice, scoria, and tuff. Synthetic lightweight aggregate can be manufactured by thermal treatment from a variety of material such as clay, diatomite, perlite, vermiculite, blast-furnace slag, and fly ash pellets.

2.3 Oil Palm Shell (OPS)

Oil palm shell is one of the wastes generated from oil palm milling process (Sahu *et al*., 2011). Malaysia is the second largest palm oil producer in the world in year 2006 (43%) after Indonesia (44%) (Lee, 2009), involving 4.4 million hectares (2008) and is expected to increase every year (Mustaffa *et al*., 2011). Palm oil and its related products represent the largest export of Malaysia, which generate RM80 billions of income for commodity export in 2011.The main products produced by the palm oil mills consist of not only crude palm oil and oil palm kernel, but also huge quantities of residues such as oil palm fibre, shell and empty fruit bunches as shown in Figure 2.1 (Abdullah *et al*., 2011). For instance, about 19 million tonnes per year of crop residues consist of empty fruit bunch, fibre and shell (Mustaffa *et al*., 2011). It is estimated that over 4.56 million tonnes of OPS is produced annually (Teo *et al*., 2006).

The processing of oil palm is divided into four main stages: sterilisation and stripping; digestion, clarification and pressing; depericarping and nut cracking, the process shown in Figure 2.2 (Abdullah, 2011). The fruit bunch contains (by weight) about 21% palm oil, 6–7% palm kernel, 14–15% fibre, 6–7% shell and 23% empty fruits bunch (Husain *et al.*, 2002). The shell has different shapes and has low density, and is directly attained by breaking the oil palm shell with machinery (Mannan and Ganapathy, 2004).

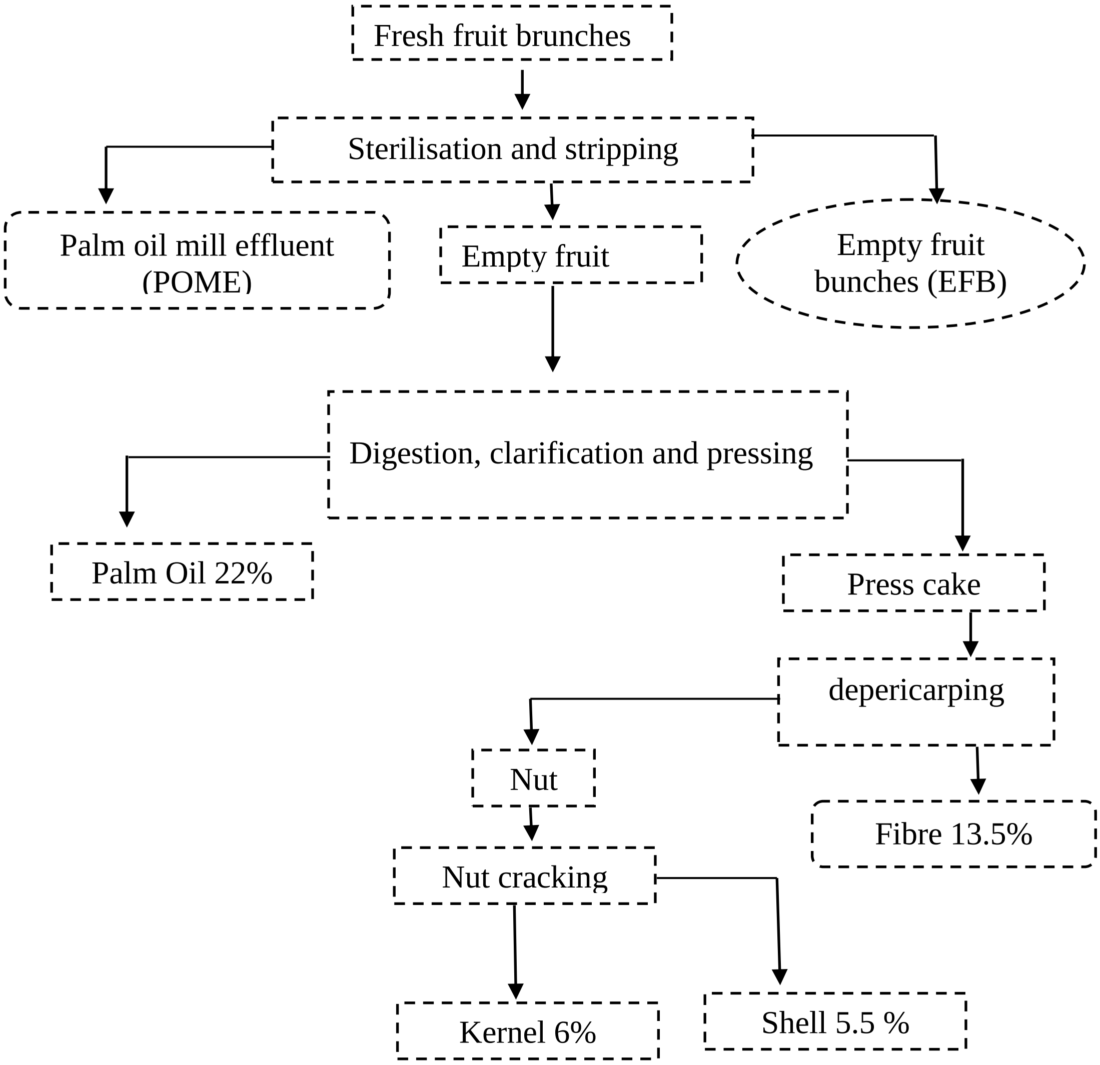

Figure 2.2: Flow diagram of oil palm processing in the oil palm mill

(Abdullah *et al*., 2011)

2.4 OPS Physical Properties

2.4.1 Shape, size and texture

The shape of OPS aggregate varies: irregular flaky shaped, angular, circular or polygonal. It depends on the extraction method or breaking of the nut (Okpala, 1990; Okafor, 1988; Basri *et al.,* 1999). The thickness of OPS varies between 0.15 and 8 mm depending on the species of oil palm tree and time of the year. However, in average, the thickness is between 2 and 3 mm. To obtain the size of OPS used as coarse aggregate, the OPS were sieved using a 2.36 mm sieve to remove the OPS aggregate with less than 2.36 mm in size (Shafigh *et al*., 2011a). The shell is fairly smooth for both concave and convex surface although the broken edge is rough and spiky (Shafigh *et al*., 2010). Generally, the surface texture remains fairly smooth in both the concave and convex part of the shell.

2.4.2 Bulk Density

In terms of loose and compacted bulk density and specific gravity (Table 2.2), OPS is found to be lighter than conventional coarse aggregate and this is because of higher porosity of OPS. This shows that OPS is approximately 40% lighter than conventional aggregate based on bulk density ranges. Loose and compacted bulk densities of OPS aggregate varies in the range of 500–600 kg/m^3 and 600–740 kg/m^3 respectively (Mannan and C.G, 2002 & Gunasekaran et al., 2011). Generally, bulk densities are also affected by size of OPS (Shafigh *et al*., 2014). Due to lower density of OPS, the density of concrete made from OPS usually falls in the range of 1600–1900 kg/m^3 (Clarke, 1993).

Table 2.2: Physical properties of oil palm shell (Alengaram *et al*., 2013)

Author (Year)	Specific Gravity	Loose Bulk Density (kg/m³)	Compacted Bulk Density (kg/m³)	Moisture Content (%)	Water Absorption 24 h (%)	Porosity (%)
Abdullah (1988)	-	-	620	-	-	-
Okafor (1988)	1.37	5.12	589	-	27.3	-
Okpala (1990)	1.14	545	595	-	21.3	37
Basri et al. (1990)	1.17	-	595	-	23.32	-
Mannan & Ganapathy (2002)	1.17	-	592	-	23.32	-
Teo et al. (2008)	1.17	500–600	-	-	33	-
Ndoke (2006)	1.62	-	740	9	14	28
Jumaat et al. (2008)	1.37	566	620	8–15	23.8	-
Mahmud et al. (2009)	1.27	-	620	-	24.5 (10–12)	-
Alengaram et al. (2010)	1.27	-	620	-	25	-
Gunasekaran et al. (2011)	1.17	-	590	-	23.32	-
* Granite Stone	2.67–2.82	1472–1650	1300-1450	-	0.76	-

2.4.2 Water absorption and water content

Olanipekun *et al.* (2006) reported OPS moisture content of 4.35%. It is higher compared to conventional granite that has less than 1% (Neville, 1995). The shell has 24 h water absorption capacity range of 18–33%. This means that OPS has high water absorption compared to conventional gravel aggregate that has water absorption of less than 4% (Neville, 1995). However, Portland Cement Association (1979) suggested the absorption capacity of lightweight aggregate at 5–20%. This value shows that high water absorption of OPS could be due to high pore content. Okpala (1990) further reported that the porosity of the shell is 37%.

2.4.3 Mechanical properties

OPS aggregate impact value of 3.51–7.86% is lower than conventional aggregate which is 45%. Again it is because of the shape (concave and convex surface) of OPS that makes the toughness of the impact decrease. For abrasion value of OPS, it is 3.1% and lower than conventional aggregate which is 32.7% (Okpala, 1990). The lower the value, the more abrasion-resistant the aggregate is. Other researchers' findings are shown in Table 2.3, and the results show that the OPS abrasion value (12.5%–33%) and aggregate impact value (23.2%–49%) are lower than granite stone, respectively.

Table 2.3: Mechanical properties of oil palm kernel shell (Alengaram *et al.*, 2013)

Author (Year)	Abrasion Value (Los Angeles) %	Aggregate Impact Value (AIV) %	Aggregate Crushing Value (ACV) %
Okafor (1988)	-	6	10
Okpala (1990)	3.05	-	4.67
Basri et al. (1990)	4.8	-	-
Mannan & Ganapathy (2002)	4.8	7.86	-
Olanipekun (2005)	3.6	-	-
Mannan et al. (2006)		1.04–7.86	-
Ndoke (2006)		4.5	
Teo et al. (2006 & 2007)	4.9	7.51	8
Jumaat et al. (2008)	8.02	3.91	-
Mahmud et al. (2009)	-	3.91	-
*Granite stone	24	16.8	-

2.4.4 Chemical content and thermal conductivity

Chemical composition of OPS is as shown in Table 2.4. Based on the chemical composition, OPS will have positive reaction with ordinary Portland cement, but negative reaction with additional fly ash as partial cement replacement for compressive strength (Basri et al., 1999).

OPS also has low thermal conductivity of 0.19 W/m°C, while OPS concrete obtained from 1:1:2 (cement:sand:shell) and w/c 0.5% has thermal conductivity of 0.45 W/m°C which is in the range of thermal conductivity for lightweight concrete (0.05–0.69 W/m°C) (Okpala, 1990). Thus, it is very useful as coarse aggregate in lightweight concrete for thermal insulation purpose.

Table 2.4: Chemical composition of OPS aggregate (Teo *et al*., 2007)

Elements	Results (%)
Ash	1.53
Nitrogen (as N)	0.41
Sulphur (as S)	0.000783
Calcium (as CaO)	0.0765
Magnesium (as MgO)	0.0352
Sodium (as Na_2O)	0.00156
Potassium (as K_2O)	0.00042
Aluminium (as AI_2O_3)	0.13
Iron (as Fe_2O_3)	0.0333
Silica (as SiO_2)	0.0146
Chloride (as CI^-)	0.00072
Los on Ignition	98.5