PERFORMANCE OF OIL PALM SHELL LIGHTWEIGHT AGGREGATE CONCRETE CONTAINING POFA AS PARTIAL CEMENT REPLACEMENT TOWARDS CARBONATION, WATER ABSORPTION AND CORROSION

ZUL AIDA BINTI IBRAHIM @ HIM

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Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

Palm Oil Fuel Ash (POFA) and Oil Palm shell (OPS) is q waste generated from oil palm mill which then disposed at landfill and create pollution to environment. Integration of POFA as partial cement replacement in OPS lightweight aggregate concrete(LWAC) production gives double benefit in form of cutting cost by reducing the uses of cement and reduce the ending at waste landfill in Malaysia. The present research investigates the performance of OPS LWAC containing POFA towards carbonation, water absorption and corrosion. Two types of mixes has been used in the research that the plain OPS and OPS with 20%POFA. Four types of curing methods namely water curing, spray curing, air curing and natural weather curing has been used to determine the effect of different curing methods towards carbonation and water absorption of specimen. Performance of OPS containing 20% POFA towards corrosion has been investigated using impressed voltage test method. Integrating of 20% POFA as partial replacement by using water curing method results in lower water absorption value and carbonation. Application of water curing enable better pozzolonic reaction and produces larger amount of C-S-H gel making the concrete denser and durable compared to normal concrete. Plain concrete and OPS LWAC with 20% POFA has shown a sign of corrosion. Both concrete the performances of both OPS and OPS with 20% POFA need to be observed for longer period of time.

ABSTRAK

Abu terbang kelapa sawit dan tempurung kelapa sawit merupakan sisa buangan daripada kilang kelapa sawit dan menjadi satu isu yang memberi masalah kepada persekitaran. Abu terbang kelapa sawit yang mempunyai potensi untuk dijadikan bahan separa yang bersifat seperti simen telah diguna pakai dalam membuat konkrit ringan tempurung kelapa sawit, dapat menyelesaikan masalah peningkatan bahan terbuang ke tapak pelupusan dan mengurangkan penggunaan simen. Kajian ini berkaitan penyiasatan terhadap prestasi konkrit ringan tempurung kelapa sawit terhadap karbonasi, penyerapan air dan daya tahan terhadap hakisan. Dua jenis bancuhan yang digunakan dalam kajian ini ialah konkrit ringan tempurung kelapa sawit dan konkrit ringan tempurung kelapa sawit yang mengandungi 20 peratus abu terbang kelapa sawit. Empat jenis pengawetan yang digunakan iaitu pengawetan air, pengawetan udara, pengawetan semburan dan pengawetan cuaca semulajadi yang digunakan untuk mengkaji karbonasi dan kadar penyerapan air terhadap konkrit ringan tempurung kelapas sawit. Penyiasatan keupayaan konkrit yang yang mengandungi 20% abu terbang kelapa sawit terhadap proses pengaratan menggunakan ujian keberkesanan voltan. Dengan menggunakan kaedah pengawetan air, kehadiran 20 peratus abu kelapa sawit didalam konkrit ringan mendapati kadar penyerapan air dan karbonasi berkurang. Pengawetan air membantu proses reaksi pozzolonik dan menghasilkan kuantiti kalsium silikat hidrat gel yang banyak dan membuatkan konkrit lebih padat dan tahan perbanding konkrit biasa.

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LIST OF SYMBOLS

%	Percentage
Gt	Gigatonnes
μm	Micro meter
^0C	Degree celcius
m^2	Metre square
kg	Kilogram
mm	Milimeter
hr	Hour

LIST OF ABBREVIATIONS

OPS	Oil palm shell
LWAC	Lightweight aggregate concrete
POFA	Palm oil fuel ash
OPC	Ordinary Portland cement

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Malaysia is known as the richest country with oil palm plantation and has potential to become the huge production of oil palm industry in the future. According to Ramli, (2003) Malaysia itself produces 4 million tons of OPS annually. However this industry generates abundant waste of palm oil fuel ash (POFA) and oil palm shell (OPS) which causes pollution to the environment. POFA is obtained from the burning of pressed fibre and shell which are used as fuel to generate electricity required for the operation of the mill Tanghchirapat *et al.*, (2009) An OPS comes from the hard shells directly reaped by breaking the palm kernel shell with specific machinery. POFA is agrowaste ashes that contain a large amount of silicon dioxide and has a potential to be used as a cement replacement Tangchirapat *et al.*, (2007). Cement as we know is produced from raw materials and hence these resources will be depleted in the future. The findings about the POFA as partial cement replacement can help to produce more environmental friendly concrete and can reduce the waste management problem of palm oil mill.

The OPS which is very light and directly available from the palm oil industry waste have the potential to be a lightweight aggregate, lightweight aggregate concrete (LWAC) Abdullah (1984). The structure performance of OPS LWAC has been investigated by Teo *et al.*, (2010). Research on oil palm shell lightweight aggregate concrete (OPS LWAC) has been continuously evolving with the creation of greener of OPS LWAC through the creation of greener OPS LWAC through incorporation of slag Shafigh *et al.*, (2013) and fly ash Shafigh *et al.*, (2013) as partial cement replacement. Recently Muthusamy and Azimah,(2014) discovered that POFA of 20% can be used as partial cement replacement in OPS LWAC. However, the effect of POFA towards carbonation, water absorption and corrosion yet to be discovered. This research looks into the effect of different curing regime on carbonation, water absorption of OPS LWAC containing POFA. The durability of the concrete towards corrosion attack is also studied in this study.

1.2 PROBLEM STATEMENT

Raw materials and alternative fuels are involved in cement manufacture; these natural resources would deplete in the future. Due to the lack of resources, the price for the cement and market demand are increasing year by year. In addition, the cement industry sector releases 2.37 Gt of total pollutants to the environment in 2000 Kim *et al.*, (2002). Thus it is evident that, the production of cement is not an environmentally friendly to the living things. On the other hand the OPS and POFA which is a waste from the Oil Palm Industry is disposed in landfill and need more space if there is no way to overcome the problem. Integrating POFA in OPS LWAC production would reduce palm oil waste ending as waste.

1.3 OBJECTIVE OF THE STUDY

The objective of the study is as follows;

a) To investigate the effect of different curing regime to carbonation of OPS LWAC containing POFA as partial cement replacement.

b) To investigate the effect of different curing regime to water absorption of OPS LWAC containing POFA as partial cement replacement.

c) To investigate corrosion resistance of OPS LWAC containing POFA as partial cement replacement.

1.4 SCOPE OF STUDY

Tests have been conducted to determine the effect of POFA as partial cement replacement towards resistance of LWAC to carbonation, water absorption and corrosion attack. Two type of mixes used, is LWAC without POFA which acts as a control and the other mixes 20% of POFA replacement. For carbonation and water absorption test, specimens have been exposed to four types of curing regime namely water curing, spray curing, air curing and natural weather curing. The corrosion resistance of OPS LWAC containing POFA has been investigated using impressed voltage test.

1.5 SIGNIFICANCE OF STUDY

Using POFA as partial cement replacement reduces the palm oil wastes ending at landfill. The palm oil wastes can reduce the use of raw materials for OPS LWAC production. Utilization of POFA in OPS LWAC would reduce a more environmental friendly concrete.

1.6 LAYOUT OF THESIS

This report consists of five chapters. Chapter one introduces the issue investigated in this research highlighting problem statements and outlining objective to be achieve. Scope of research and contribution of the study is also included in this section. The chapter ends with the layout of thesis. Chapter two discusses the utilization of OPS and POFA in concrete production. This includes the review of basic properties and application of LWAC. Carbonation, water absorption and corrosion problem of concrete is defined and the review on these issues presented in this chapter.

Chapter three discusses the methodologies used in this study. The preparation of mix ingredients and the apparatus used in conducting the experiment is reported in this section. The testing procedures adopted are also discussed in chapter three. Chapter four mainly presents and discusses about the laboratory results of OPS lightweight aggregate concrete incorporated with POFA. Data that has been analysed and made in form of graph for carbonation and water absorption test result is presented in this chapter. Results on the durability performance of OPS LWAC containing POFA towards corrosion attack is presented and analysed.

Chapter five concludes the whole study. The conclusions are drawn with respective objectives listed based on the results obtained from the testing. The recommendations for future study have been listed in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter consists of information gathered about oil palm shell and palm oil fuel ash from oil palm factory until the concrete production. Others subtopic presented the review on characteristics, properties, utilization of palm oil agrowastes and also about carbonation, water absorption and corrosion attack.

2.1 POFA AS CEMENT REPLACEMENT MATERIAL

The Palm oil industry produces palm oil fuel ash result from the burning process of palm fibre, shells and empty fruit bunches. The main purpose of the burning is to generate electricity for that factory where pressed fibre and shell is burned under 800-1000 °C. POFA is a by-product obtained from the combustion of palm fibre, shell and empty fruit bunches Tanghchirapat *et al.*, (2009). In addition, POFA which contains a large amount of silicon dioxide and has been accepted as a pozzolonic material in concrete Adepegba, (1989). Many researchers represent their own finding and investigation towards the uses of POFA in concrete materials.

2.1.1 POFA from Malaysia Palm Oil industry

According to Ramli, (2003) Malaysia is predicted to have nearly 5 million hectares of palm oil plantation by the year 2020. This estimated amount will contribute to the large amount of oil palm wastes too. After extracting the oil from the fresh palm fruit, the empty bunches fibre and shell are burned to produce steam fo generating electricity for the mill. According to Yin *et al.*, (2008) utilization of POFA in Malaysia as fertilizer for agriculture purposes also has been investigated in order to reduce the environmental load.

The ashes collected from the burning process are known as POFA. Based on mixing composition, about 516 thousand tonnes of boiler ash or POFA in 2006 Nazri *et al.*, (2010) is produced. Almost 5% of waste ash obtained and then disposed of in open fields causing traffic hazard besides problems in health leading to bronchitis and lung diseases Tay and Show, (1995).

2.1.2 Characteristics of POFA

The physical properties of OPC and POFA are tabulated in Table 2.1. The particle size distribution of OPC, unground and ground POFA is illustrated in Figure 2.1. The scanned electron micrographs (SEMs) of the particle shape of ordinary Portland cement (OPC), ground and unground POFA is presented in Figure 2.2, 2.3 and 2.4 respectively.

Table 2.1: Physical properties of OPC and POFA

Properties	**OPC**	**Unground POFA**	**Ground POFA**
Colour	Grey	Light grey/whitish	Dark grey
Specific gravity	3.14-3.28	1.78-1.97	2.22-2.78
Median particle size, d_{50} (μm)	10-20	54.3-183	7.2-10.1
% Passing through 45- μm sieve (% mass)	-	5.6-58.8	97-99
Specific surface area, Blaine (m^2/kg)	314-358	796	882-1244
Strength activity index (%)	-	-	78.6-115
Soundness, Le Chatelier expansion (mm)	0.45-1	0.5-2.6	1

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

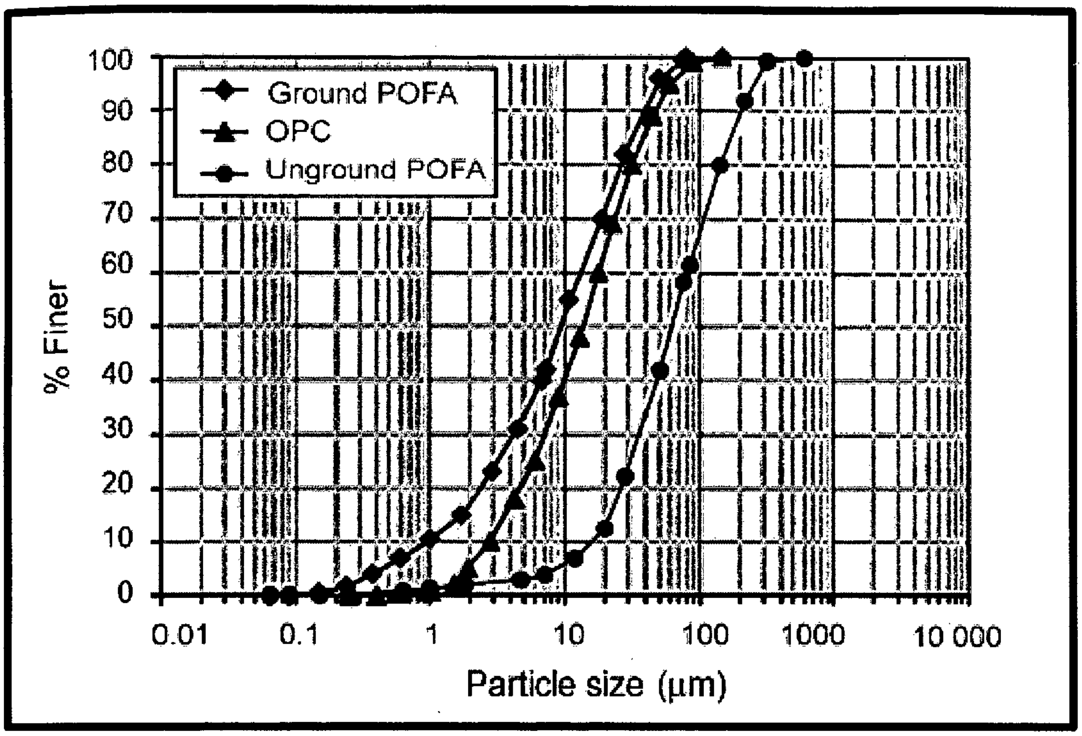

Figure 2.1: Particle distribution of OPC, and unground and ground POFA

Source: Sata *et al.*, 2004

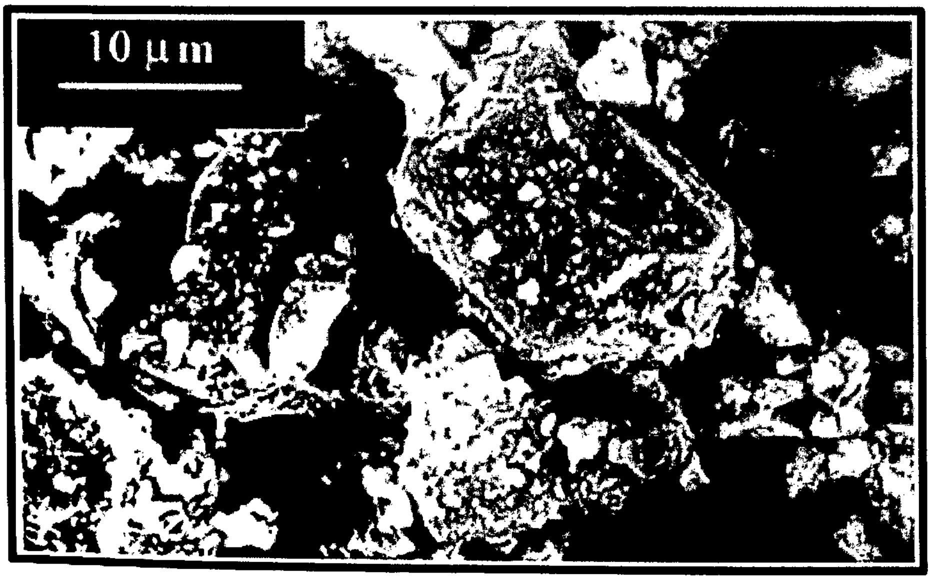

Figure 2.2: Ordinary Portland cement

Source: Chindaprasirt *et al.*, 2007

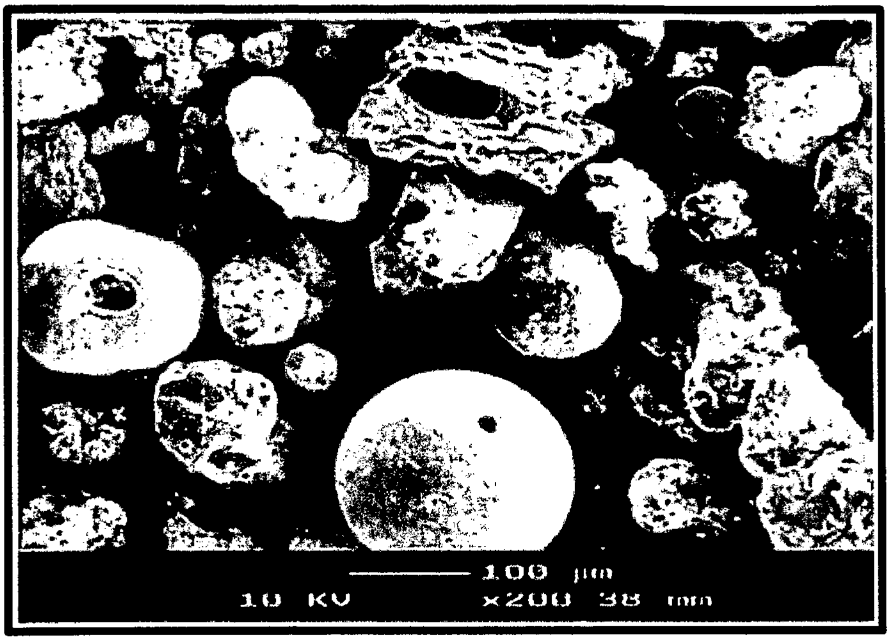

Figure 2.3: Scanned electron micrographs (SEMs) unground POFA

Source: Jaturapitakkul et al., 2007

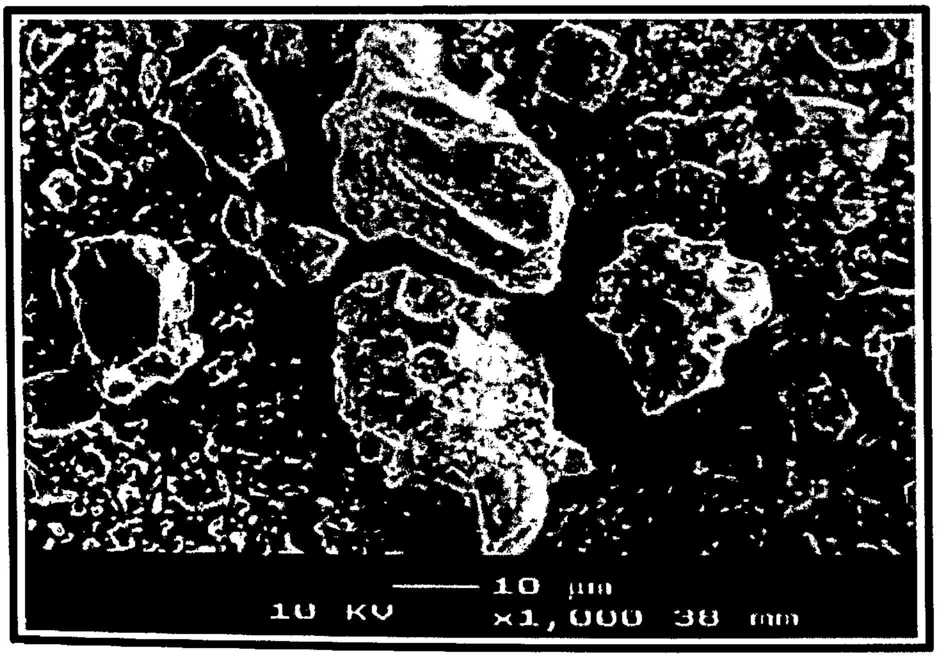

Figure 2.4: Scanned electron micrographs (SEMs) of ground POFA

Source: Jaturapitakkul et al., 2007

The Table 2.2 represents the total amount of $SiO_2+Al_2O_3+Fe_2O_3$ was 69.7% with LOI 10% and SO_3 4.0% within the limit. The difference of the composition depends on the fineness of the ground POFA. According Chindaprasirt et al., (2004) POFA can be classified as Class N (natural) pozzolan.

Table 2.2: Chemical composition of material (%)

Component	OPC	POFA
Silicon dioxide(SiO_2)	20.9	65.3
Aluminium oxide	4.7	2.5
Iron oxide	3.4	1.9
Calcium oxide	65.4	6.4
Magnesium oxide	1.2	3.0
Sodium oxide	0.2	0.3
Potassium oxide	0.3	5.7
Sulphur trioxide	2.7	0.4
Loss on ignition (LOI)	0.9	10.0
$SiO_2 + Al_2O_3 + Fe_2O_3$	-	69.7

Source: Tangchirapat and Jaturapitakkul, 2010

2.1.3 Utilization of POFA in Concrete

The adaptation of POFA as partial cement replacement in Malaysia began in 1990 Tay, (1990). Many laboratory investigations showed that POFA can be used in producing strong and durable concrete due to its adequate pozzolonic property Hussin and Awal, (1997). The diversity of POFA nowadays evolves in high strength concrete, aerated concrete and high performance concretes. Table 2.3 shows the finding on the utilization of POFA as partial cement replacement for various types of concretes.

Table 2.3: Use of POFA as partial cement replacement

Type of concrete	Researchers	Remarks
Normal concrete	Abdul Awal (1996)	Integrating 30% POFA increase the strength of concrete
High strength concrete	Sata *et al.*, (2004)	Integrating 20% POFA gives higher strength.
High strength concrete	Weeachart *et al.*, (2009)	Integrating 20% POFA gives 59.5-64.3MPa at 28-day 70MPa at 90-day
Aerated concrete	Mohd Warid *et al.*, (2009)	20% of POFA as partial cement replacement.
Recycle aggregate concrete	Weeachart *et al.*, (2012)	20% POFA replacement, compressive strength 7% lower than conventional

2.2 OPS from Malaysia Palm oil Industry

The oil palm industry is important in many countries such as Malaysia, Indonesia, and Nigeria. According to Teo e*t al.*, (2006) over 4.56 million tonnes of OPS waste are produced annually. OPS is the waste product produced during extracting palm oil, which originates from the oil palm tree Okafor, (1988). The OPS waste from Malaysia oil palm factory is estimated at 3.13 million tons Mannan, (2001). Figure 2.6 shows the global scale of palm oil production between 1996 and 2000 (Chavalparit, 2006). Figure 2.5 illustrate the abundant OPS which dumped as a waste.

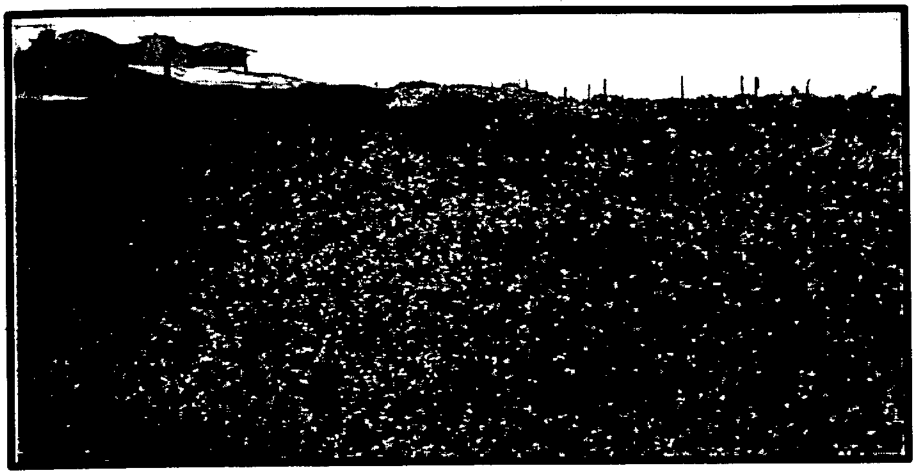

Figure 2.5: The great mass of oil palm shells (OPS) in the palm oil mill area

Source: Payam et al., 2010

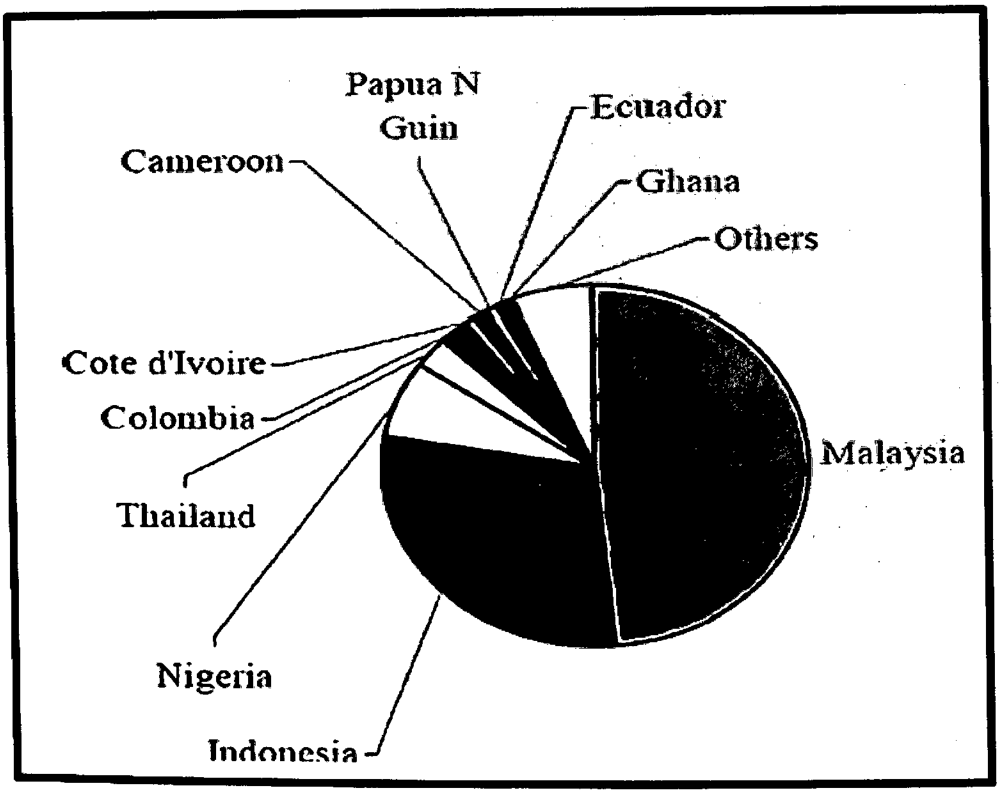

Figure 2.6: World palm oil production 1996-2000

Source: Payam et al., 2014

2.2.1 Characteristics of OPS

The colour of OPS ranges from dark grey to black. The surface of OPS is smooth for convex faces and concave faces, but the broken edge is rough and spiky. The different breaking pattern of OPS produces different shapes such as angular, polygonal etc. The thickness of OPS depends on the species of palm tree and it is about 0.15 - 8mm (Basri *et al.*, 1999; Okpala, 1990).

The shell has a higher water absorption compared to conventional gravel aggregate. Shell has a 24 h water absorption capacity range of 21- 33 %, while conventional aggregate has less than 2 % Neville, (2008). The high level of absorption could be due to the high pore content. The loose and compacted bulk densities of OPS between ranges 500-550, 590-620 kg/m^3 with specific gravity of 1.14- 1.37. OPS with higher porosity and lower densities conclude that the OPS are approximately 60% lighter than conventional aggregate. The densities of shell are within the range of typical lightweight aggregates (Okpala, 1990) Figure 2.7 shows the OPS grain with and without fibre and Figure 2.8 represent the OPS in LWAC.

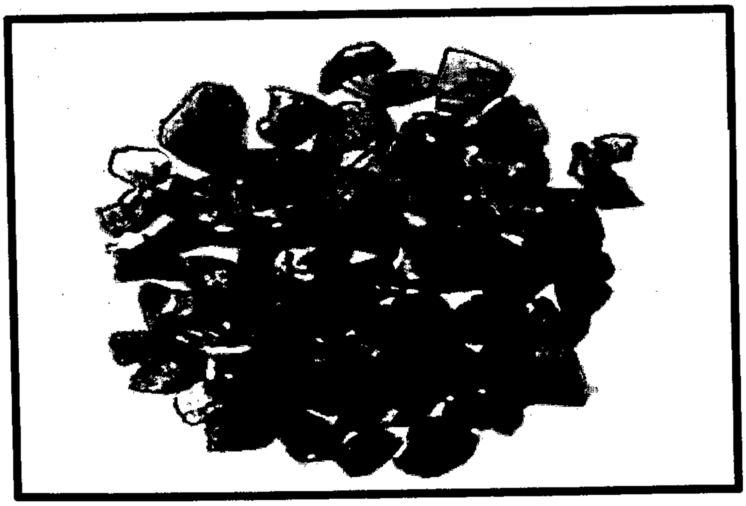

Figure 2.7: OPS crushed from old OPS

Source: Payam et al., 2014

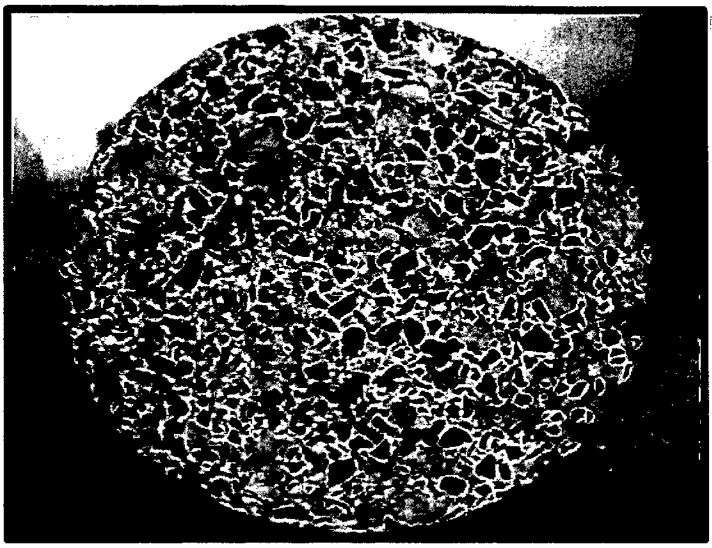

Figure 2.8: OPS grain in lightweight concrete

Source: Payam et al., 2014

The characteristics of OPS, which are hard, will reduce the risk of deterioration. Basri *et al.*, (1999) reported that the Los Angeles abrasion value of OPS and crushed stone are 4.8 and 24 % respectively. The lower the value of Los Angeles abrasion shows that the OPS have good resistance to wear. Similar to the value of aggregate impact and aggregate crushing value, OPS has a lower value compared to conventional aggregate, hence it is decided that the OPS has a good absorption to shock Teo *et al.*, (2007). The chemical composition of OPS aggregate is tabulated in Table 2.4.

Table 2.4: Chemical composition of OPS aggregate

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 Al_2O_3)	0.130
Iron (as Fe_2O_3)	0.0333
Silica (as SiO_2)	0.0146
Chloride (as Cl^-)	0.00072
Loss on Ignition	98.5

Source: Teo *et al.*, 2007

2.2.2 Utilization of OPS in concrete

The nature of OPS, which is light and applicable, has been used in lightweight aggregate concrete. OPS aggregate can replace partially or fully as an aggregate in lightweight aggregate concrete. Lightweight aggregate concrete has the potential of being used in building construction as for low cost houses, floor, slab, etc. Teo *et al.*, (2007). The presence of OPS as a coarse aggregate has reduced the demand on raw resources such as stone and gravel Teo *et al.*, (2008).

The application of OPS also has been investigated by Jumaat *et al.*, (2009) on OPS foamed concrete in comparison of the thermal conductivity with conventional materials. Besides that, the OPS also now are evaluated for high strength lightweight concrete (HSLWC). The HSLWC can be obtained by crushing old OPS which have no fibre and hence increase the bond between the cement matrix or by crushing large old OPS and reduce the maximum size of coarse OPS aggregate. The utilization of OPS in concrete production is shown in table 2.4.