EFFECT OF WATER CON[illegible] F OPS CONCRETE
CONTAINING PALM OIL FUEL ASH

NUR AFIQAH FATIHAH BINTI HAMIDON

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ABSTRACT

Oil palm shell (OPS) and palm oil fuel ash (POFA) generated as by product from Malaysian palm oil mills has been disposed at landfill in increasing quantity thus creating environmental pollution. Steps taken to incorporate these waste materials in concrete production would be able to reduce the amount of waste disposed at landfill. This thesis presents an experimental study on the performance of OPS concrete consisting POFA as partial sand replacement material at different water cement ratio. OPS concrete has been considered as control mix. Another mix is OPS concrete consisting five percent of POFA. A total of 96 concrete cubes have been tested in this study. The performance of OPS POFA concrete in term of workability, compressive strength, and moisture absorption when different water cement ratio used have been investigated. The results demonstrate that the workability for OPS POFA samples increase as the water cement ratio increased. Increase in the water cement ratio added causes reduction in the compressive strength and water absorption of OPS POFA concrete.

ABSTRAK

Tempurung kelapa sawit (OPS) dan abu kelapa sawit (POFA) adalah bahan buangan yang dijana oleh kilang pemprosesan kelapa sawit di Malaysia. Peningkatan kuantiti bahan buangan ini di tapak pelupusan telah menyebabkan pencemaran alam sekitar. Pendekatan yang diambil untuk menggunakan bahan buangan ini dalam penghasilan konkrit berupaya mengurangkan jumlah pelupusan sisa buangan di tapak pelupusan. Tesis ini membentangkan kajian tentang kesan kandungan nisbah air simen terhadap sifat-sifat konkrit OPS yang mengandungi POFA sebagai bahan pengganti separa pasir. Sifat-sifat yang telah dikaji adalah kebolehkerjaan, kekuatan mampatan, dan penyerapan lembapan. Konkrit OPS telah dijadikan sebagai konkrit kawalan. Satu lagi campuran adalah campuran konkrit OPS yang mengandungi lima peratus POFA. Sejumlah 96 kiub konkrit telah diuji dalam kajian ini. Keputusan ujikaji menunjukkan bahawa kebolehkerjaaan untuk sampel OPS POFA meningkat apabila nisbah air simen bertambah. Peningkatan dalam nisbah air simen yang ditambah menyebabkan pengurangan kekuatan mampatan dan penyerapan air oleh konkrit OPS POFA.

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LIST OF SYMBOLS

%	Percentage
°C	Celcius
kg	Kilograms
m	Meter
m^3	Meter cubes
MPa	Mega Pascal

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standards
BS EN	British Standard European Norm
DOE	Department of Environment
LOI	Loss on Ignition
OPC	Ordinary Portland Cement
OPS	Oil Palm Shell
POFA	Palm Oil Fuel Ash
RHA	Rice Husk Ash
EFB	Empty Fruit Bunch
FFB	Fresh Fruit Bunch
HMA	Hot Mix Asphalt
W/C	Water Cement Ratio
Al_2O_3	Aluminium Oxide
CaO	Calcium Oxide
$Ca(OH)_2$	Calcium Hydroxide
CaO	Calcium Oxide
Cl-	Chloride
C-S-H	Calcium Silicate Hydrate
Fe_2O_3	Ferric Oxide
K_2O	Potassium Oxide
MgO	Magnesium Oxide
MnO_3	Magnesium Trioxide
N	Nitrogen
Na_2O	Sodium Oxide
Na_2O_3	Sodium Trioxide
S	Sulphur
SO_3	Sulfite
SiO_2	Silicon Oxide
TiO_2	Titanium Dioxide

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Malaysia is recognized as the world's largest producer and exporter of palm oil, with oil palm planted in over 4.3 million hectares of land (MPOB, 2009). To date there are more than two hundred mills operating in this country (Husin and Awal, 1997). At the mills, when the fresh fruit bunches (FFB) are processed and oil extraction takes place, solid residues and liquid wastes are generated. Oil palm shell (OPS) and palm oil fuel ash (POFA) are among the solid waste which is disposed in increasing quantity. Shafigh (2011) reported that OPS is abundantly available in Malaysia. POFA disposed as waste in landfill also cause environment problem (Karim, 2011). Government needs to allocate more hectares of landfill for disposal and spends a lot of money for transporting the waste and also maintenance purposes. Moreover large amount of untreated waste from agriculture and industrial sectors contaminate land, water and air by means of leaching, dusting, and volatilization.

By using OPS and POFA in production of concrete for the in use construction industry, the amount of the solid waste disposed can be reduced. It can be seen that, utilization of these wastes into concrete material production would be able to decrease amount of waste ending up at landfill. Reduction in the amount of waste disposed would minimize the environmental pollution and provide cleaner environment. Thus this study would be focusing on investigating the properties of concrete containing OPS and POFA as mixing ingredient.

1.2 PROBLEM STATEMENT

Malaysia is the world's largest oil palm producer. The total area planted with oil palm in Malaysia covers about 2.6 million hectares, with capability of OPS production of over 4 million tons annually. In addition, POFA produced from combustion of palm oil plant residues is generated in huge volume (Sata, 2004). Most of these agro wastes disposed in landfills cause a potential health hazard and environmental problems.

At the same, the growing construction industry has lead towards utilization increasing amount of construction material especially concrete. The utilization of concrete has results in consumption of large amount of natural aggregate, thus creating the depletion of natural aggregate. In Sabah alone, the annual aggregate usage has reached about 12 million tonnes (Mannan, 2010). Use of OPS and POFA as partial aggregate replacement would be able to reduce the utilization of natural aggregate in concrete production.

1.3 OBJECTIVES

The related objectives of the present research are as the following:

i. To investigate the effect of water content towards workability of OPS concrete containing POFA as partial sand replacement.
ii. To determine the effect of water content towards compressive strength of OPS concrete containing POFA as partial sand replacement.
iii. To determine the effect of water content towards moisture absorption properties of OPS concrete containing POFA as partial sand replacement.

1.4 SCOPE OF STUDY

This study concentrates on investigating the effect of water content on the behavior of OPS concrete containing palm oil fuel ash (POFA) as partial fine aggregate replacement. The OPS concrete composes of cement, water, sand, coarse aggregate and 10% OPS are considered as a control mix. Meanwhile, OPS concrete containing sand replacements by 5%with POFA is studied. Water cement ratio selected to be used is 0.50, 0.55, 0.60, and 0.65 to obtain various categories of workability.

All the fresh mixes were subjected to slump test, vebe test, and compacting factor test to measure the workability. The mixes which then prepared in forms cubes were tested for compressive strength. Finally, the moisture absorption properties of OPS concrete containing POFA as partial concrete replacement were examined.

1.5 SIGNIFICANCE OF STUDY

In developing countries where abundant OPS and POFA are discharged, these materials can be used as partial aggregate replacement material in concrete production for the use in construction industry. The utilization this waste in construction material would reduce amount of waste thrown thus creating healthier environment. Besides that, these wastes would be an alternative material to reduce the use of natural aggregate in order to prevent depletion of natural resources and maintain ecological balance. Reduced building cost and optimization the usage of plant agricultural waste in the production of green construction material would be extra benefit that can be gained through this approach.

1.6 LAYOUT OF THESIS

Chapter one is the introduction part that consists of problem statement, objective, scope of study, and significance of research. Chapter two describes the summary of literature reviews on key topics related to the OPS concrete and POFA concrete. It provides a context for the research, to justify the research and illustrate how the concrete containing the OPS and POFA have been studied previously. On overall, it depicts the findings on the physical characteristic and chemical composition of both OPS and POFA beside the utilization of palm,oil waste in the construction industry. At the end of the chapter, the summary of the literature review is concluded.

Chapter three present in detail the apparatus, materials, sample preparation, and laboratory test that have been carried out to achieve the outline objectives. All the tests elaborated in this chapter are in accordance to the procedure outlined in the existing standard. Chapter four elaborates on the results obtained from the experimental programme. The results on the workability, water absorption, and compressive strength of OPS concrete containing POFA as partial fine aggregate replacement have been discussed. Finally, chapter five present the conclusion of the study together with recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete is one of the most popular construction materials. In 1999, Kosmatka reported over six billion tons of concrete are made each year, amounting to the equivalent of one ton for every person on earth, and powers a US$35 billion industry which employs over two million workers in the United States alone. However, approximately 80 per cent of the resources used today in construction industry are non-renewable. Due to the scarcity of conventional raw materials, there is a great opportunity to explore the alternatives of renewable resource. This alternative resource includes industrial waste products, agricultural solid waste and recycled aggregates, particularly from the demolition and building waste.

Currently, solid waste from palm oil industry namely palm oil fuel ash (POFA) and oil palm shell (OPS) has been introduced and developed as particle substituent in concrete. These abundantly available wastes have lead towards numerous researches in integrating these wastes in concrete making. So far studies have been conducted by adding POFA as partial cement replacement in normal concrete (Awal, 1996), high strength concrete (Sata et al., 2006), and aerated concrete (Abdullah et al., 2004). Structural lightweight consisting OPS as coarse aggregate replacement has also been developed by Teo et al. in 2006. However no effort has been taken to investigate both OPS and POFA as mixing constituent in concrete.

2.2 PALM OIL INDUSTRY WASTE

Oil palm is introduced earlier into the country in 1917 (Mohd Jaafar, 1994). It is the prime crop choice for the diversification program. Today, Malaysia is recognized as the world's largest producer and exporter of palm oil, with oil palm planted in over 4.3 million hectares of land. East Malaysia alone, comprising of the states of Sabah and Sarawak, has coverage of about 1.9 million hectares (MPOB, 2009; Malaysian Oil Palm Statistic, 2007). Hence, over half of the world's total palm oil is produced from the oil palm industry in Malaysia.

The production of oil palm results in large quantity of agriculture waste. Every year about 90 million metric tons of trunks, shells, husks, palm press fibers, and empty fruit bunches are produced in this tropical country. At the mills, when the fresh fruit bunches is processed and oil extraction takes place, solid residues and liquid wastes are generated. These agro wastes include empty fruit bunches, fiber, shell, and effluent (Mahlia et al., 2001). Most of these wastes are dump into environment without any potential reuse. For the disposal purpose, a lot of money is spent to transport these wastes. The abundance of these wastes has created crucial environmental issues such as fouling and attraction of pests. In addition, huge land area becomes ineffective and the fertility of land is reduced day by day.

Limited effort had been carried out in the past to use these waste as building materials in the construction industry. The utilization of waste as raw material can help to decrease the solid waste problem. For example, the utilization of OPS in concrete can help to overcome the over dependence on depletable natural resources such as stone aggregate (Teo et al., 2008). In this respect, Universiti Malaysia Sabah built a small footbridge in 2001 and a low cost house in 2003, both using OPS concrete. Hence, the utilization of agro waste from palm oil provides a holistic solution to the problem of natural resources depletion and gain economical benefit.

2.2.1 Oil Palm Shell

Waste oil palm shell (OPS) is produced in large quantities from the agriculture industry every year. In Malaysia alone, over 4 million tonnes of waste OPS are generated annually. Oil palm shell is the end product of oil palm manufacturing process. The oil palm yields about 19 tonnes/hectare of fresh fruit bunch (MPOB, 2009; Malaysian Oil Palm Statistic, 2007). The fresh fruit bunch generally contains about 5.5% shells (Singh et al., 2009). Figure 2.1 shows the surface structure of OPS.

Figure 2.1: Oil palm shell

2.2.1.1 Characteristic

Okafor (1988), described oil palm shell to have irregular shape after cracking and therefore its shape cannot be defined. The shape takes pattern of cracking on the shell and usually composed of many shapes ranging from parabolic or semi-circular shapes, flaky shapes and other irregular shapes. After cracking the edges of the shells are rough and spiky and the overall shape becomes concave and convex with a fairly smooth surface.

Generally, light weight nature of OPS aggregate has a unit weight of less than 2000 kg/m^3, which is approximately 60% lighter compared to the conventional crushed stone aggregate (Shafigh et al., 2010). Their colour ranges from dark grey to black. The strength, thickness and density of OPS aggregate are lower than that of crushed stone aggregate which are the important factors for the compressive strength in concrete. The shells are of different shapes depending on the breaking pattern of the nut. The surfaces of the shells are fairly smooth for both concave and convex faces. However, the broken edge is rough and spiky. The thickness varies and depends on the species of palm tree from which the palm nut is obtained and ranges from 0.15 - 8 mm (Basri et al., 1999; Okpala, 1990).

An OPS is hard in nature and does not deteriorate easily once bound in concrete and therefore, it does not contaminate or leach to produce toxic substances (Basri et al., 1999). The characteristic of OPS aggregates are different compared to other lightweight aggregates, such as expanded clay, expanded shale, and sintered pulverized fuel ash, which are artificially produced. The smooth surface of OPS may have led to a better workability. OPS aggregate is porous in nature and therefore have low bulk density. The physical characteristic and chemical composition of OPS are illustrated in Table 2.1 and Table 2.2 respectively.

Table 2.1: Physical characteristic of OPS

Physical Properties	
Properties	**OPS**
Maximum aggregate size, mm	12.50
Shell thickness, mm	0.50 – 3.00
Bulk density, kg/m^3 590	590.00
Specific gravity (SG), saturated surface dry	1.17
Fineness modulus	6.08
Los Angeles abrasion value, %	4.90
Aggregate impact value (AIV), %	7.51
Aggregate crushing value (ACV), %	8.00
24-hour water absorption, %	33.00

Source: Teo et al. (2007)

Table 2.2: Chemical composition of OPS

Chemical Composition	
Elements	**Concentration (%)**
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)	0.13
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)

2.2.1.2 Application in Industry

The large quantity of OPS waste has led to studies focusing on the possible use of this waste as aggregates in concrete production. Tu et al. (2006) reported that the concrete industry globally would consume around 8 to12 billion tonnes annually of natural aggregates after the year 2010. Utilization of OPS as coarse aggregate replacement would be able to reduce the consumption of natural aggregate. A number of studies (Okafor, 1988; and Basri et al., 1999) have found that OPS could be used as structural lightweight concrete.

There is economical achievement from the production of low cost houses. A model low-cost house of 58.68 m^2 area which was built in Sarawak, Malaysia using 'OPS hollow blocks' for walls and 'OPS concrete' for footings, lintels and beams was performing well and has no structural problems at all (Mannan and Ganapathy; 2001). Mannan (2002) proposed that concrete made with oil palm shell as coarse aggregate can be used for the construction of low-cost houses, farm structures, tennis courts, pavements, blocks and paving drains; which results the reduction of production cost. Basically, incorporation of OPS in production of concrete for the use in building construction would able to reduce the consumption of natural aggregate and also decrease the amount of OPS ending up at landfill.

2.2.2 Palm Oil Fuel Ash

Palm oil fuel ash (POFA) is an agro-waste resulting from the combustion of oil palm plant residue in palm oil industry. It is obtained from burning of palm oil husk and shell. After the extraction of oil from oil palm fruit, both husk and shell are burn in boiler to produce steam for the turbine engine, which generates electricity for use in palm oil mills (Mahlia et al., 2001). About 5% POFA by weight is produced after combustion. Currently, thousands tonnes of ash are produced annually. This ash has been simply disposed as waste materials at landfill thus causing environmental problems (Salihuddin and Hussin, 1993). Figure 2.2 illustrate POFA disposed as a waste by the palm oil mill.

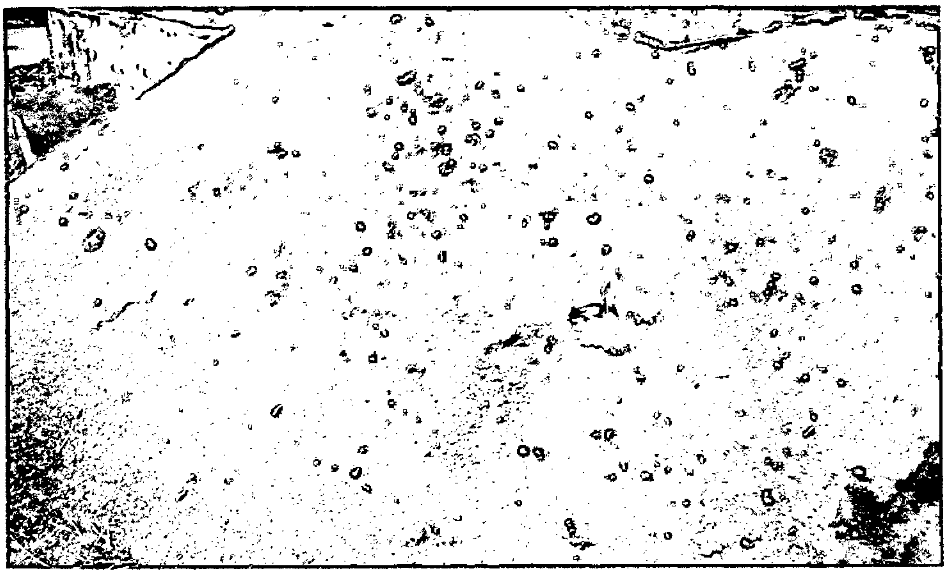

Figure 2.2: Palm oil fuel ash

2.2.2.1 Characteristic

In general, unground POFA is light gray because of the unburned carbon content left at a relatively low burning temperature. The colour becomes dark gray in the case of ground POFA (Abdullah et al., 2006). The physical characteristic of POFA is very much influenced by the operating system in palm oil factory. POFA has low pozzolanic property due to its large particle size and porous structure. However, the quality of POFA can improved by grinding until the median particle sizes were 19.9 and 10.1 microns. Hence, it can improve the pozzolanic reaction. Table 2.3 shows the properties of POFA.

The major chemical composition of POFA is SiO_2, about more than 50%. Thus, it is considered to possess high potentials of serving as a cement replacement. Moreover, most of the ashes contained total amount of SiO_2, Al_2O_3, Fe_2O_3 less than 70%. Specified this should be minimum 70% for class N pozzolan. POFA satisfied the requirement of pozzolana, and may be grouped in class C pozzolan as specified in ASTM C618-01 (2001). Researchers (Tay, 1990; Awal, 1997; and Chindaprasirt, 2007) found that POFA has pozzolanic properties and could be used as a replacement of Portland cement in concrete.

Table 2.3: Properties of palm oil fuel ash

Elements	Concentration (%)
SiO_2	57.8
Al_2O_3	4.6
Fe_2O_3	3.3
CaO	6.6
MgO	65.3
SO_3	4.2
Na_2O_3	0.3
K_2O	8.3
LOI	10.1

Source: Chindaprasirt (2007)

2.2.2.2 Application of POFA in Industry

Since end of 20^{th} century investigation on the use of POFA as partial cement replacement in normal concrete (Awal, 1996) high strength concrete (Sata et al., 2004), and aerated concrete (Abdullah et al., 2006) have been carried out. Sata et al. (2004) investigated the behavior of high-strength concrete with POFA and showed that the concrete containing up to 30% ground POFA provided a higher compressive strength than ordinary Portland cement concrete. Awal and Hussin (1999) used to POFA to produce high performance concrete with reasonably a good durability. In addition, Mat Yahaya (2003) used ground POFA in aerated as partial sand replacement concrete production.

The continuous investigation has also highlighted that POFA can also be used in other construction material such as bricks and stone mastic asphalt (Ismail et al., 2010; Kamaluddin, 2008; Nasly and Yassin, 2009). Ismail et al. (2010) produced bricks with satisfactory compressive strength using POFA and paper sludge. Nasly and Yassin (2009) reported that POFA can be incorporated in interlocking blocks for use in sustainable housing. Besides, Kamaluddin (2008) used POFA as a filler material to produce stone mastic asphalt with enhanced stability, stiffness, and tensile strength.

Studies conducted by Ismail et al. (2010) also found that bricks fabricated by incorporating 20% paper sludge and 20% POFA into cement provide adequate compressive strength, tolerable water absorption and acceptable heavy metals leachate, thereby depicting significant potentialities to serve as masonry unit elements. Success in integrating this waste material in production of various type of construction material would be able to reduce amount of waste ending up at landfill.

2.2.3 Oil Palm Clinker

Palm oil clinker is the agro waste from burning of fibers and husks inside the boiler under very high temperature in order to generate the steam engine for oil extracting process (Mohammed et al., 2010). It is a light solid fibrous material which when crushed has the potential to be used as aggregate in lightweight concrete. The use of clinker by combining with cement can be form into useful material would be able to minimize wastes, maximize recycling, enhance environmental sustainability and ease the economic pressure. Figure 2.3 show the surface structure of palm oil clinker.

Figure 2.3: Palm oil clinker

2.2.3.1 Characteristic

Palm oil clinker is a lightweight and porous material. It tends to absorbs water and gave significant effects to the concrete properties especially to its durability. It also has light density with specific gravity compared to conventional aggregates. Since palm oil clinker come in a big size and it is crushed to a maximum size of 20 mm is used as coarse aggregate and size below 5 mm is used as fine aggregate. The clinkers are flaky and irregular shaped. The broken edges are rough and spiky (Robani and Chee, 2009). The major chemical composition of oil palm clinker is SiO_2. Thus, it is considered to possess high potentials of serving as a cement replacement. The physical characteristic and chemical composition are shown in Table 2.4 and Table 2.5 respectively.

Table 2.4: Physical characteristic of palm oil clinker

Physical Characteristic		
Properties	**Fine Clinker**	**Coarse Clinker**
Aggregate size (mm)	<5	5 - 14
Bulk density (kg/m^3)	1118.86	781.08
Specific gravity (SSD)	2.01	1.82
Fineness modulus	3.31	6.75
Moisture content (%)	0.11	0.07
Water absorption (24 h)	26.45	4.35
Aggregate impact value (%)	-	25.36
Aggregate crushing value (%)	-	18.08

Source: Mohammed et al. (2010)

Table 2.5: Chemical composition of palm oil clinker

Chemical Composition	
Element	**Concentration (%)**
SiO_2	81.8
Fe_2O_3	5.18
K_2O	4.66
Al_2O_3	3.5
CaO	2.3
MgO	1.24
SO_3	0.76
TiO_2	0.17
Na_2O	0.14

Source: Robani and Chee (2009)

2.2.3.2 Application in Industry

In Malaysia, studies on the utilization of using palm oil clinker as lightweight aggregate in construction industry, especially in structural application started about 30 years ago (Kamaruddin, 1991). The significant usage of clinker as the artificial lightweight aggregate in HMA in road pavement will benefit us from the aspect of waste management from palm oil mill and minimize the demand on natural aggregate in the road construction industry (Omar et al., 2001). Continuous research conducted to explore the potential of this waste as one of the concrete making ingredient would contribute to waste reduction.

2.2.4 Empty Fruit Bunch

Malaysia is the highest producer of empty fruit bunch (EFB) if compared to the other Asia countries such as Indonesia and Thailand. Approximately 5 million of EFB was produced by palm oil industry in 2005 (Food and Agriculture Organization, 2005). Malaysia. EFB represent about 9 percent of the total palm oil waste each year (Lim, 2000). By assuming 7 percent of fresh fruit bunches are the dry weight of EFB (Tanaka, 2006), Malaysia had produced about 1.34 tonnes per hectare (dry weight) of EFB in year 2007 and about 1.41 tonnes per hectare (dry weight) of EFB in year 2008.