CHEMICAL PRE-TREATMENT ON PALM OIL CLINKER AS PARTIAL CEMENT REPLACEMENT MATERIAL IN MORTAR

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Thesis submitted in fulfillment of the requirements

for the award of the degree of

B. Eng. (Hons.) Engineering Technology (Infrastructure Management)

Faculty of Engineering Technology

UNIVERSITI MALAYSIA PAHANG

JANUARY 2019

ACKNOWLEDGEMENTS

All praise to Almighty for granting the author an opportunity, good health and ability to complete this research and write this thesis for her undergraduate level. The author wishes to express her sincere acknowledgement and thanks to her supervisor, Associate Professor Dr Andri Kusbiantoro with unlimited guides, knowledge and moral support from starts until the end conducting this final year project research.

Secondly, the author would like to express her deepest gratitude to her parent, Mahmudin bin Mat Daud and Nor Azizan Binti Jaafar for giving her moral support mentally and physically, courage and endless love throughout her entire life. Not forget to her siblings, niece and nephew for support and encouragement to finish her study.

Last but not least, the author would like to give credits to Universiti Malaysia Pahang (UMP) for providing facilities to complete her final year project research. Also to the technical lab assistants and staff for helping and preparing materials for her to complete her study.

Lastly, a big thanks given to her final year project team for lending her help in doing her laboratory works and also to her senior, Amalina Hanani bt. Ismail with endless help, guides and knowledge from starts till the end of her final year project research.

ABSTRAK

Pengeluaran simen semakin meningkat dari hari ke hari disebabkan perkembangan bandar yang pesat. Permintaan yang tinggi dalam pengeluaran simen mengeluarkan lebih banyak karbon dioksida ke persekitaran yang membawa kepada persekitaran yang tidak sihat. Dalam masa yang sama, kesalahan dalam melupus bahan buangan pepejal berlaku secara berturut-turut telah mengakibatkan pencemaran berlaku. Klinker Minyak Sawit adalah bahan buangan kilang minyak kelapa sawit yang boleh didapati dalam kuantiti yang besar di Malaysia dan ia dianggap sebagai sisa pepejal yang tidak digunakan. Oleh itu, dengan menyalurkan sisa pepejal ke dalam industri pembinaan sebagai bahan pengganti simen dapat membantu mengatasi masalah tersebut. Tujuan kajian ini adalah untuk mengkaji kesan abu klinker minyak sawit yang dirawat dan tidak dirawat ke dalam campuran mortar berdasarkan kekuatan mampatan dan keliangan yang dibandingkan dengan campuran mortar konvensional. Pada dasarnya, proses pra-rawatan kimia dijalankan untuk merangsang reaksi pozzolanic silika amorf dengan kalsium hidroksia dalam mortar. Pra-rawatan abu klinker kelapa sawit dilakukan dengan menggunakan asid hidroklorik yang bertujuan untuk mengeluarkan elemen pelemah yang boleh memberi kesan kepada kekuatan dan kemampatan mortar di samping membantu mengekstrak silika dari abu klinker. Abu klinker kelapa sawit kemudiannya dicampur bersama 0.1 M asid hidroklorik selama 1 jam sebelum ia dikeringkan dalam oven bagi menghasilkan abu klinker yang dirawat untuk bahan gantian simen. Mortar dicampur dan dibancuh dalam 50 mm x 50 mm x 50 mm acuan dan dibiarkan selama 24 jam untuk proses pengerasan. Spesimen direndam di dalam air selama 3, 7, 28 dan 56 hari berturut-turut sebelum dibawa keluar untuk ujian kekuatan mampatan dan ujian keliangan. Keputusan menunjukkan bahawa pada peringkat awal, tindak balas pozzolana untuk T5, T10 dan T15 lebih cepat berbanding spesimen kawalan. Reaksi mula perlahan pada hari ke-28 hingga hari ke-56 dan menyebabkan kekuatan mampatan maksimum dicapai tertinggi oleh sampel kawalan. Lebih banyak silika amorf yang membentuk ikatan C-S-H pada peringkat awal menjadikan mortar lebih kuat dan lebih padat. Walau bagaimanapun, T5 dan T10 masing-masing dapat mencapai 98% kekuatan daripada spesimen kawalan. Perlu diingatkan bahawa penggunaan POCP mengurangkan kekuatan mampatan pada kadar yang biasa. Data statistik membuktikan bahawa tiada perbezaan ketara dalam kekuatan mampatan spesimen kawalan dan T5 dalam mortar. Selain itu, keputusan pada keliangan menunjukkan bahawa peningkatan jumlah POCP ke dalam campuran mortar telah mengurangkan penyerapan air ke dalam mortar akibat tindak balas pozzolana yang berlaku melalui pembentukan gel C-S-H. Penggantian peratusan tinggi POCP tidak dapat membentuk mortar yang lebih kuat kerana struktur berliang yang mengakibatkan ikatan yang lemah di antara zarah abu klinker dan zarah simen. Akhir sekali, penyelidikan ini menunjukkan bahawa POC boleh digunakan sebagai bahan pengganti simen kerana ia merupakan bahan yang sangat bermanfaat yang memberi sumbangan besar kepada persekitaran dan pembangunan mampan. Kesimpulannya, dengan menggunakan 0.1 M asid hidroklorik pada tempoh 1 jam untuk proses pra-rawatan, penggantian yang paling optimum dicapai oleh T5 kerana keupayaannya dalam menghasilkan 98% kekuatan mampatan daripada sampel kawalan dan juga dengan kurangnya liang dalam mortar.

ABSTRACT

The production of cement is increasing day by day due to the rapid urban expansion. Highly demands in cement production emits more carbon dioxide to the environment thus leads to the unsustainable environment. At that time, improper disposal of solid waste materials results on the pollution to occur consecutively. Palm Oil Clinker (POC) is a by-product of palm oil mill which can be found in large quantity in Malaysia and it is considered as waste. Hence, by channelling the solid waste into the construction industry as cement replacement materials helps to overcome those problems. The aim of this research is to study the effects of treated and untreated palm oil clinker ash into the mortar mixture based on the compressive strength and porosity comparing to that conventional mortar mixture. Basically, chemical pre-treatment process is conducted to stimulate the pozzolanic reaction of amorphous silica with calcium hydroxide in the mortar. The pre-treatment of palm oil clinker ash is conducted by using hydrochloric acid (HCl) which purposely to remove heavy metals that present in the ash beside helps in extracting a high amount of silica from the ash. The ash was then impregnated in the dilution of 0.1 M hydrochloric acid for 1 hour before it was dried in oven forming treated ash for the cement replacement material. POCP were studied at various replacement levels of treated and untreated POCP at 5%, 10% and 15% of the original total weight of the Ordinary Portland cement respectively. The mortar was mixed and cast in 50 mm x 50 mm x 50 mm mould and left 24 hours for the hardening process. The specimens are demoulded and left cured for 3, 7, 28 and 56 days consecutively before it was taken out for the compressive strength and porosity testing. The results indicate that at the early stages, the pozzolanic reaction for T5, T10 and T15 is faster than the control specimen thus resulting in higher compressive strength. The reaction starts to slow down at day 28 up to day 56 causing the maximum compressive strength attained the highest by the control samples. More amorphous silica forming the additional calcium-silicate-hydrate (C-S-H) bond at the early days making the mortar stronger and denser. However, T5 and T10 able to gain 98% of the control specimen strength respectively. It should be noted that the use of POCP reduced the compressive strength at a remarkable rate. The statistical data proved that there was no significant difference in compressive strength of the control specimen and T5 in the mortar. While the results on porosity show that increase in the amount of POCP into the mortar mixture had reduced the water usage into the mortar due to the pozzolanic reaction that took place through the formation of C-S-H gel. Replacement of high percentage of POCP unable to form a stronger mortar due to a porous structure that results in poor interlocking bond and poor blending properties between ash particles and cement particles. Last but not least, this research reveals that the POC can be used as cement replacement materials as it is a highly beneficial material contributing substantially toward the sustainable environment and development. To conclude, by using 0.1 M of hydrochloric acid at 1-hour duration for pre-treatment process, the most optimum proportion is attained by T5 because of its ability to produce 98% of control samples' compressive strength and also with the presence of fewer voids in the mortar.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BS	British Standard
C-S-H	Calcium Silicate Hydrate
D	dry mass
EFB	Empty Fruit Bunches
FA	Fly Ash
FTIR	Fourier Transform Infrared Spectroscopy
HCl	Hydrochloric Acid
M	saturated mass
MF	Mesocarp Fibre
OPC	Ordinary Portland Cement
OPT	Oil Palm Trunk
OPL	Oil Palm Leaves
OPF	Oil Palm Frond
POC	Palm Oil Clinker
POCP	Palm Oil Clinker Powder
POFA	Palm Oil Fuel Ash
PKS	Palm Kernel Shell
P	porosity
RHA	Rice Husk Ash
rpm	rotation per minutes
SBGA	Sugarcane Bagasse Ash

CHAPTER 1

INTRODUCTION

1.1 Background Study

The production of solid waste materials is increasing day by day due to rapid urban expansion. Improper disposal of solid waste may lead to a negative effect on the environment as most of the waste is being non-renewable. Over the past few decades, the agricultural industry in Malaysia had evolutionary developed which helps in supporting the economy of the country (Kanadasan & Razak, 2015). According to statistics, Malaysia had produced half of the world palm oil production which is 10.8 tonnes, thus, showing Malaysia as the world's largest producer and exporter of palm oil (Abdullah & Sulaiman, 2013) Figure 1.1 shows the production of crude palm oil in Malaysian from the year 1975 to 2011.

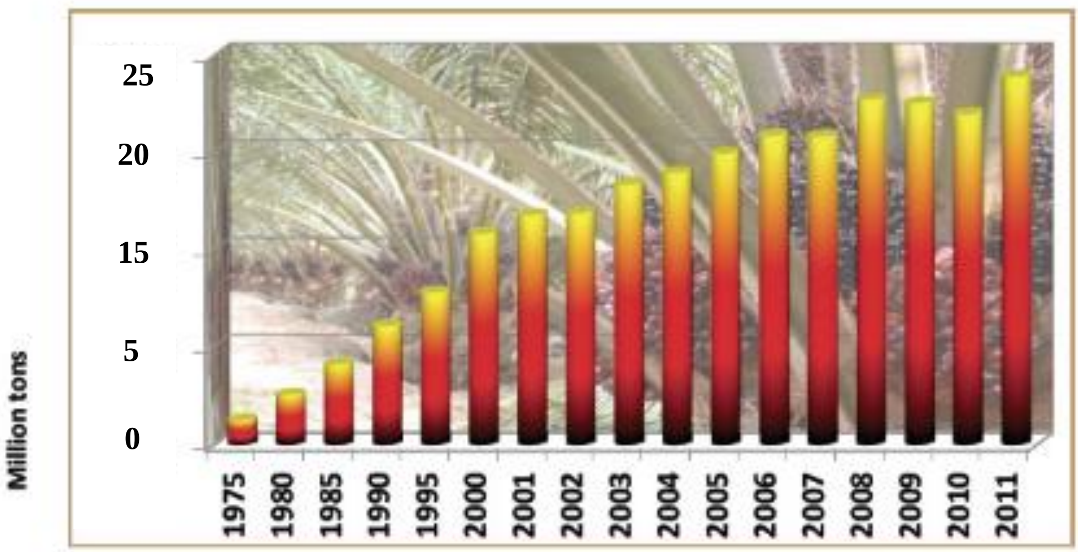

Figure 1.1 Production of crude palm oil in Malaysia
Source: MPOB (2011)

In order to sustain the fast-growing population, the production cement needed is also increasing since it is the main material used in the construction industry. Production of cement emits more carbon dioxide to the environment thus lead to negative effect such as air pollution. At a certain point, the production of cement needs to be reduced leading to an increase in cost (Ibrahim, & Razak, 2016). Engineers are the one who needs to face the problems and come out with alternatives to solve the problems regarding the depletion of naturally occur on the construction materials.

Agro-waste materials are found to be a potential construction material. Palm Oil Clinker is parts of the palm oil ash waste that can be recycled for partial replacement of cement. Reducing the usage of cement through substitution with the solid waste material can help to reduce the carbon emissions by 52% (Kanadasan & Razak, 2015). Furthermore, it can also promote to sustainable environment besides helps in overcoming disposal of solid waste material problems. In order to recycle the solid waste material, a few stages of pre-treatment need to be conducted as to remove undesirable components. Since the palm oil clinker may consist of hazardous components, prior treatment is necessary in order to increase the strength of the concrete. Excessive presence of elements such as aluminium and sulphate may affect concrete integrity.

The aim of the research is to replace cement partially with solid waste material as well as improved the properties of the concrete in term of compressive strength and porosity. Partial replacement of cement allows to reduce concrete production costs and advances ecological benefit.

1.2 Problem Statement

Generally, Ordinary Portland Cement (OPC) is used in every construction activities. Highly demand for OPC makes its production is increasing rapidly day by day. However, the production of OPC particularly produced a high percentage of carbon emission to the environment, thus making it a non-environmental friendly material. At that time, the disposal of solid waste materials is also increasing either from sources of municipal waste or agricultural waste. For instance, palm oil clinker is one of the agricultural waste that had not been discovered for the recycling purpose.

Accordingly, to overcome those problems, waste material that had not been purposely recycled after its production is recommended to undergo a chemical pre-treatment process to make it as a reactive material that can partially replace a certain percentage of Ordinary Portland Cement (OPC) in the concrete mix. Besides, using this organic material can help to reduce the carbon emission to the environment and ensure healthier living. Thus, the outcome of this study will benefit in the reduction of Portland cement usage and its non-environmentally friendly production, consecutively.

1.3 Objectives

The main objective of this study is to evaluate the palm oil clinker ash as a cement replacement material. To achieve this main objective, there are three sub-objectives that need to be fulfilled.

1. To determine the optimum acid parameter to pre-treat the palm oil clinker ash based on its silica content.
2. To attain the compressive strength and porosity of concrete containing pre-treated palm oil clinker ash.
3. To determine the optimum proportion of pre-treated palm oil clinker as cement replacement material in mortar based on its compressive strength and porosity properties.

1.4 Scope of Study

The scope of the study is important as to briefly explain the detail of the study that has been conducted. The scope of this study is defined as follow:

i. The waste material used was palm oil clinker, collected from industrial oil palm factory located at Felda Lepar Hilir, Gambang, Kuantan, Pahang.
ii. Palm oil clinker ash was impregnated with hydrochloric acid (HCl) of different concentration (0.1 M, 0.5 M, and 1.0 M) for 1 to 3 hours each.
iii. The percentage amount of clinker bottom ash used to partially replace the cement in the concrete were 5%, 10%, and 15% for treated and untreated palm oil clinker.
iv. The mortar trial mix test was cured within 3, 7, 28 and 56 days to observe its compressive strength gained for each sample of different percentage substitution of Portland cement.
v. Porosity testing was conducted to determine the percentage of water that able to seep into the void of the mortar for 7 and 28 days.
vi. X-ray Fluorescence (XRF) is conducted to analyze the chemical oxide composition of palm oil clinker powder.
vii. The sample preparation was conducted at Concrete Lab and Toxicology Lab, Universiti Malaysia Pahang.

1.5 Research Significance

Highly usage of Ordinary Portland Cement (OPC) in construction industry leads to pollution and thus make it as a non-environmental friendly material. The purpose of the study is to reduce the consumption of Ordinary Portland Cement (OPC) by replacing it partially with palm oil clinker ash beside able to determine its effect on compressive strength and porosity of the mortar. An alternative method to replace a certain amount of cement with the solid waste material can help to minimize the problems and at the same time contribute to a sustainable development country.

Palm Oil Clinker Ash (POCP) is selected to be cement replacement material and pre-treatment process is conducted to remove undesirable material from the ash beside enhancing the pozzolanic reaction to occur in the mortar. This research is said to be different than the previous study as most of the researchers are not conducting a pre-treatment process before substituting the ash into the mortar mixture. Pre-treatment process helps to improve the concrete integrity and enhance the pozzolanic reaction afterwards. Improper disposal of waste material will pollute the environment while the production of too much cement will emit more carbon dioxide (CO_2) to the environment, thus, affect the health living concurrently. Replacing OPC with palm oil clinker ash is one of the innovations that can leads to the sustainable country as it can be implemented at all types of concrete works since cement is a basic material used in every construction activities.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete generally made up of 3 major elements which are cement, aggregate, and water. Cement is one of construction material that is very popular and widely used all around the world. The production of cement which is the main element in the concrete are recorded to be increasing day by day due to the high demand in the construction industry. Consequently, the cost of producing this cement is also increasing and gives an effect on the development industry. Therefore, industrial by-product (fly ash, flag, and silica fume) and biogenic wastes (palm oil fuel ash, rice husk ash, and palm oil clinker) have become significant to be used for supplementary cementing materials in the concrete industry (Karim, et al., 2012).

Concrete can be engineered to fulfil the needs of the client, engineer, and architect as compared to the other materials such as steel and stone which it generally has to be used naturally as they are. Mineral elements that presence in Portland cement such as tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferrite play a crucial role in the mixture since chemical reaction that occurs will help in producing a high quality of concrete as desirable. The primary product of cement hydration is complex and poor in the formation of calcium silicate hydroxide gel (C-S-H) while the secondary cement hydration is calcium hydroxide with a highly crystalline material.

In this new era, an idea to proposed "green concrete" is widely known among expert people. Since concrete is by far the highest demand material in the world, this idea can somehow reduce the production of ordinary Portland cement. According to Kanadasan & Razak, (2015), Ordinary Portland cement can cause global warming effect since approximately 1 ton of carbon dioxide (CO_2) is released to the environment and thus give a big effect to the worldwide. The sustainable environment can be achieved by implementing a green element in the construction industry by taking some innovation in making a “green concrete” for a future generation afterwards. From Figure 2.1 below, it shows that the level of replacement affects the carbon emission to the environment and engineering environmental index. As to be observed from the figure below, the higher the replacement level, the better the engineering environmental index and the lesser the carbon emission.

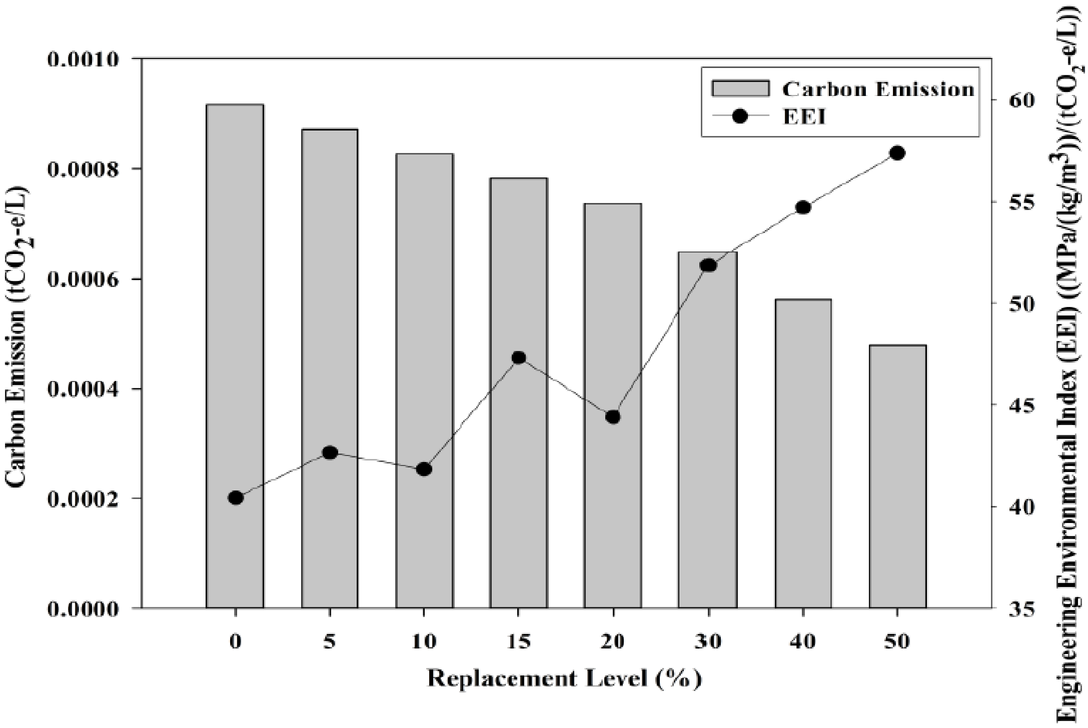

Figure 2.1 Carbon emissions of specimens incorporating POC powder with engineering environmental index (EEI)

Source: Kanadasan & Razak (2015)

2.2 Pozzolanic Material

Pozzolan generally comprises natural and artificial materials. Nowadays, the most common pozzolan used is industrial by-products. The pozzolanic material has little or no cementing properties, but small particle size of the pozzolan encourage the reaction of calcium hydroxide with the presence of moisture at the ordinary temperature forming a cementing properties materials. Pozzolan that generally made up from agriculture waste can replace the role of cement as a binder of concrete due to the high percentage of silica content present in its chemical properties elements (Munir, et al., 2015).

Recently, many researchers had conducted some research regarding palm oil clinker ash (Kanadasan & Razak, 2015), palm oil fuel ash (Mohamed Idris, et al., 2016) and rice husk ash (Ephraim, et al., 2012). From their study, it shows that most of the supplementary material used contains a high amount of silica. The presence of silica in the material allows the pozzolanic reaction to occur. The pozzolanic reaction is a chemical reaction that occurs during the mixing process of mortar due to the presence of siliceous or alumino-siliceous material. It is in finely divided form and in the presence of moisture, chemically reacts at ordinary temperatures with calcium hydroxide (released by the hydration of Portland cement) to form compounds possessing cementing properties (Snellings, 2016). The high pozzolanic reaction can help to increase the mechanical properties of concrete as it converts silica-rich precursor with no cementing properties to a calcium silicate, with a good cementing property (Embong, et al., 2015). The formation of C-S-H bond within the mixture helps to fill in the void presence in the mortar, thus making it stronger as compared to the control mortar sample. Figure 2.2 depicts different types of biomass produced by various industry in Malaysia.

Hydraulic reaction:

$$\text{OPC} + \text{water} \rightarrow \text{C-S-H} + \text{CH} + \text{other hydrates} \quad 2.1$$

Pozzolanic reaction:

$$\text{Pozzolan} + \text{CH} + \text{water} \rightarrow \text{C-S-H (Calcium Silicate Hydrate)} \quad 2.2$$

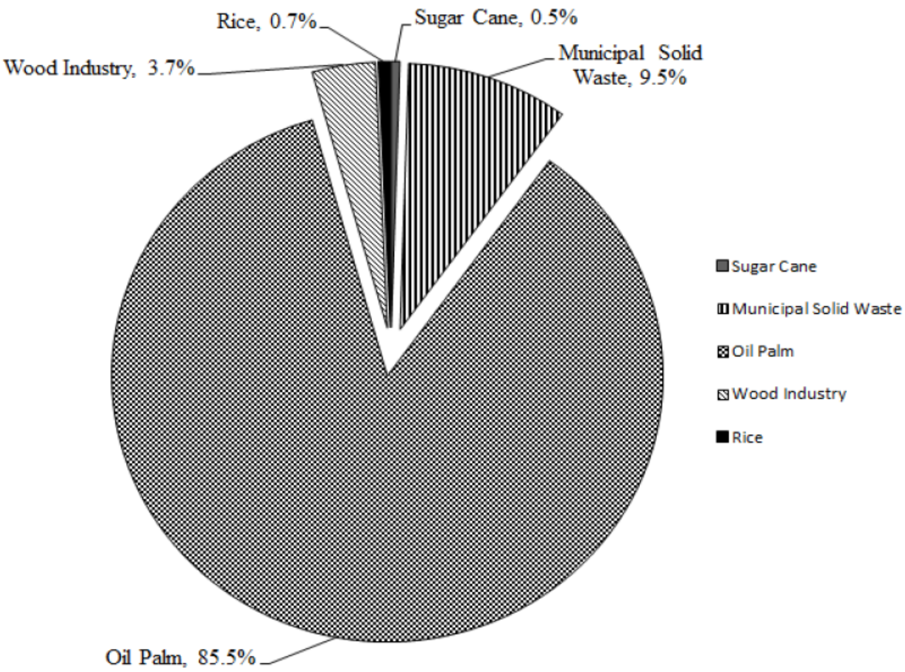

Figure 2.2 Biomass produced by different industries in Malay

Source: Kanadasan & Razak, (2015)

2.2.1 Industrial Waste

Industrial waste materials are waste produced from any industrial activities which are disposed and not purposely used especially from manufacturing processes such as factories, industries mills, and mining operations. Basically, the most famous industrial waste used as supplementary cement replacement either in replacing cement or aggregate are fly ash, ground granulated blast furnace slag, and coal bottom ash.

2.2.1.1 Fly Ash

Fly Ash (FA) is a spherical, irregular-shaped by-product produced by the burning process of coal-generated from the plants. The impurities float out from the combustion chamber and then cools forming a solid spherical glassy particles. It is a man-made volcanic material which possesses weak or non-self-cementing ability but able to form gel formed from the reaction with $Ca(OH)_2$. The physical characteristic of fly ash varies due to some factors such as coal type, boiler type, operating condition and post-combustion condition (Xu & Shi, 2018).

Some researcher has conducted a few procedures for pre-treatment process. According to research conducted by Lam, et al., (2011), fly ash needs to undergo pre-treatment process in order to remove chloride, salt, and sulphate as it will affect the quality of the concrete. The pre-treatment process is called washing pre-treatment where water is used as a leaching agent. While, a study conducted by Cretescu, et al., (2018), chemical characterization is conducted by using sodium hydroxide (NaOH) as part of the alkali activation process and the most optimum parameter obtained was 10 M at 45 ^{o}C. Table 2.1 shows the chemical and physical composition of fly ash.

Fly Ash mostly shows positive results in compressive strength and its porosity. At an early age, fly ash shows a lower compressive strength as compared to the control sample, but increasing in curing days has made the concrete stronger than the control samples consecutively (Kabay, et al., 2015). The porosity of concrete containing fly ash decrease due to pore that filled with C-S-H gel thus results in forming a denser structure (Kabay, et al., 2015).

Table 2.1 Chemical and physical composition of fly ash

Chemical elements	Percentage
SiO_2	56.67 %
Al_2O_3	20.65 %
Fe_2O_3	4.92 %
(SiO_2)+ (Al_2O_3) + (Fe_2O_3)	82.24 %
SO_3	0.06 %
Na_2O	0.07 %
CaO	3.27 %
K_2O	1.59 %
MgO	0.62 %
LOI	10.74 %
Density	2.09 g/cm3
Retained on #325 sieve	38.2 %

Source: Velandia, et al (2018)

2.2.1.2 Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast furnace slag (GGBS) is a primary waste material formed from the blast furnace of the steel and iron industries which operated commonly at 1500 ^{o}C. The materials that fed into the blast furnace generally consist of a mixture of limestone, iron ore and coke. The materials are melt in the blast furnace and the product of iron and slag are produced. A granular and glassy is formed and known as granulated blast furnace slag (GGBS) (Patra & Mukharjee, 2017). The composition of GGBS basically depends on the factors of the types of ore, the type of flux used and the unwanted materials present in the charged coke. (Ramakrishnan, et al., 2017).

Basically, GGBS is chosen for cement replacement materials due to its pozzolanic behaviour. According to Patra & Mukharjee, (2017) GGBS was found to be a good pozzolan with a high amount of silica content. Table 2.2 shows the chemical composition of GGBS as compared to cement.

Table 2.2 Chemical composition of Cement and GGBS

Formula	Concentration in %	
	Cement	GGBS
CaO	69.00	-
SiO_2	24.91	91.00
Al_2O_3	5.85	-
Fe_2O_3	0.20	-
MgO	0.04	7.73
Na_2O	-	0.12
Cr_2O_3	-	-
Cl	-	0.009
S_2^-	-	0.50
SO_2^{-3}	-	0.38
Insoluble residue	-	0.497
Loss on ignition	-	0.26
Manganese content	-	0.12
Glass content	-	91.00
Moisture content	-	0.10
Chemical Modulii		
$CaO + MgO + SiO_2$	-	76.03
$(CaO + MgO)/SiO_2$	-	1.30
CaO/SiO_2	-	1.07

Source: Patra & Mukharjee, (2017)

According to Ramakrishnan, et al (2017), 95% of blast furnace slag contains silicon, aluminium, magnesium, and oxygen. A research conducted by Patra & Mukharjee, (2017) stated that incorporation of GGBS in concrete mixture able to increase the compressive strength up to 50% replacement but beyond this amount, the strength started to decrease. Besides, the compressive strength of concrete containing GGBS was found to be stronger than the control sample. As the curing age increase, the compressive strength will increase simultaneously due to the pozzolanic reaction that took place in the concrete with the formation of C-S-H gel. While the porosity of concrete decreases as the percentage replacement of GGBS increase. This is due to the pozzolanic reaction that improved the structure of the cement and the interfacial transition zone between cement paste and coarse aggregate.

2.2.2 Agricultural Waste

Agricultural waste is produced from the various agricultural operation. Agricultural wastes are mostly a renewable type of waste that can be recycled for some purposes such as reused as fertilizer and others. A few types of agricultural waste are well functioned in industrial purpose. Rice husk ash and sugarcane bagasse ash are the examples of agricultural types of waste that contain a high percentage of silica. Presence of this element in the ash can enhance the pozzolanic reaction to occur as to be converted from non-cementitious material properties to a good cementitious material during the hydration process. Thus, it can help to improve the mechanical strength of the concrete simultaneously.

2.2.2.1 Rice Husk Ash

Rice Husk Ash (RHA) is an agricultural waste which had produced 20 million tonnes annually (Malik, et al., 2015). It has been found to be super pozzolanic and obtained from the combustion process of rice husk and it has irregularly shaped particles with many micro-pores (Ephraim, et al., 2012). Some researcher had found out that RHA able to give benefits to the environment as it can be supplementary material in concrete. Generally, RHA undergoes the incineration process in order to obtain a high amount of silica content. RHA chemically consist 50% of cellulose, 25-30% lignin and 15-20% silica (Christopher, et al., 2017). After the burning process, cellulose and lignin are removed, leaving silica ash in the RHA.

Method of incineration is very important in producing an amorphous form of silica that had the potential to be used for supplementary material in concrete. The open burning method is not encouraged as it will produce more carbon element and it might affect the concrete performance. It was investigated that the chemical composition of RHA especially silica does not influence by the geological factor or locations as most of them recorded with approximately in the same range between 85%-95% of silica (Christopher, et al., 2017). Table 2.3 shows the difference in oxide composition of rice husk ash that has been collected in Malaysia and Japan.

The production of RHA as cement replacement material can be produced in form of ash and silica gel. RHA basically has a high amount of silica element but the method of incineration process conducted is vital in order to the obtained a higher amount of Silica Dioxide (SiO_2) (Christopher, et al., 2017). On the other hand, to produce silica gel, a few steps of pre-treatment and extraction need to be conducted by using chemicals such as ethylene glycol, ethanol, alcohol, and sodium hydroxide (Laine, 2015).

Table 2.3 Chemical composition RHA from Malaysia

Parameter	Percentage Composition of RHA (%) in Malaysia	Percentage Composition of RHA (%) in Japan
SiO_2	93.1	91.6
K_2O	9.67	2.54
Fe_2O_3	0.21	0.06
CaO	0.41	0.58
Al_2O_3	0.21	0.14
MgO	2.31	0.26
Na_2O	1.59	0.09

Source: Christopher, et al., (2017)

According to research conducted by Ephraim, et al (2012), replacement of 10%, 20% and 25% of RHA from cement can produce 38.4 MPa, 36.5 MPa, and 33 MPa respectively. From the results obtained, it shows that the optimum percentage of replacement is 10% as it able to achieve the maximum compressive strength. But somehow, early reduction of compressive strength can attribute to delayed in pozzolanic activities (Christopher, et al., 2017). At day 28, the cubes might completely achieve to its maximum strength.

On the other hand, the size of pozzolan such as Rice Husk Ash (RHA) might significantly affect the pozzolanic reaction in the concrete. The bigger the surface area, the higher the water demand needed to achieve the standard consistency of mixture (Christopher, et al., 2017). The pozzolanic reaction of C-S-H that occur in the mixture helps to reduce the pores present and resulting in a dense concrete. Hence, water absorption in concrete will be reduced with a greater amount of RHA content in concrete.

2.2.2.2 Sugarcane Bagasse Ash

Sugarcane is one of fibrous waste product produced from the sugar refining agricultural industry. Mainly, the elements that present in the bagasse ash are aluminium ion and silica. The fibrous residue is used in the same industry as fuel in the boilers for heat generation leaving behind 8-10% ash as waste, known as sugarcane bagasse ash (SCBA) (Modani & Vyawahare, 2013). SCBA contains a high amount of unburnt matter such as silicon, aluminium and calcium oxide.

Table 2.4 shows the chemical composition of sugarcane bagasse ash that will be used as an aggregate replacement in the mortar. Basically, SGBA consists approximately 50% cellulose, 25% hemicellulose and 25% lignin. While, sugarcane mainly produced 26% of bagasse and 0.62% residual ash (Modani & Vyawahare, 2013).

Table 2.4 Chemical composition of sugarcane bagasse ash

Component	Mass (%)
SiO_2	62.43
Al_2O_3	4.28
Fe_2O_3	6.98
CaO	11.8
K_2O	3.53

Source: Modani & Vyawahare, (2013)

Sugarcane Bagasse Ash (SGBA) collected undergoes pre-treatment process by using hydrochloric acid (HCl) with a high concentration (0.1M to 6.0M) for 1 to 6 hours. (Embong, et al., 2015). The purpose of this method is to extract a high amount of silica and removes alkali and alkaline metals from the SGBA waste. High concentration of sulphuric acid or hydrochloric acid (1.0 M-6.0 M) is suitable to leach the waste as it enables to extract a high amount of SiO_2 up to 80% of the waste product, However, pre-treatment with 0.1 M for 1-hour results in the production of higher silica content in the ash. The higher the silica content in the ash, the higher the tendency for the pozzolanic reaction to occur, thus increasing the mechanical properties of concrete.

Compressive strength by replacing SGBA shows positive results. As stated from the previous study conducted by Modani & Vyawahare, (2013), replacing 10% of SGBA as fine aggregate in mortar able to increase the compressive strength of concrete. But, replacing aggregate with SGBA up to 20% unable to gain high strength. The compressive strength is increasing as the curing days increase simultaneously.

2.3 Palm Oil-Based Pozzolan

Malaysia is one of the palm oil producer in the world which accounts for 39% of world palm oil production and 44% of world exports (MPOB, 2011). Palm oil is produced from the mesocarp palm oil fruits which specifically called Elaneis Guineensis (MPOC, 2012). Generally, palm oil will produce wastes after the extraction process of oil from the fruits. The types of wastes produced are empty fruit bunches (EFB), palm kernel shell (PKS), mesocarp fibre (MF), palm oil mill effluent (POME), oil palm trunk (OPT), oil palm leaves (OPL), oil palm fronds (OPF) and palm oil fuel ash (POFA). Some of the wastes are left rotten for the purpose of the decomposition process as fertilizer for the palm oil trees. While, there some wastes used for generating electricity for palm oil incineration mill. The main focus of this research is palm oil .clinker which produced from the incineration of the palm oil shell as to be used for cement replacement material in a mortar.

2.3.1 Palm Oil Fuel Ash

Palm Oil Fuel Ash (POFA) is generally produced after the incineration process of pressed palm oil fibres, shells and empty fruit bunches. It is smaller, lighter like fly ash which separated using vacuum pump from the burning zone at the bottom of the boiler. POFA can be easily seen in a greyish form which can be easily carried by the wind. Most POFA is dumped in a wide open area thus make it non-environmental friendly and can somehow pollute the environment.

Presently, disposal of POFA does not give any profitable return but it does harm the environment with pollution. According to Mohamed Idris, et al (2016), approximately 2 million tonnes of palm oil fuel ash were produced annually. POFA is said to be pozzolanic material since it contains a high amount of Silicon Dioxide (SiO_2) and low amount of Calcium Oxide (CaO) as compared to Ordinary Portland Cement (OPC). The amount of SiO_2 and CaO of POFA compared to OPC are as shown in Table 2.5.

Eventually, the optimum percentage of cement replacement plays a crucial role in compromising the strength of the concrete. According to Munir, et al., (2015), utilization of 10% of Palm Oil Fly Ash (POFA) in mixes exhibits the highest compressive strength by 17.58 MPa. Overall, the most selectable percentage for the cement replacement is 10% to 15%.

Despite this, research conducted by Sumadi & Hussin, (1995) stated that the strength of concrete is influenced by the curing age. POFA had achieved maximum strength approximately on day 270 and it shows that the strength is slightly 8.5% less as compared to the maximum control strength.

Table 2.5 Chemical composition of Ordinary Portland Cement and POFA

Constituents	OPC	POFA
Silicon Dioxide (SiO_2)	16.05	51.55
Aluminium Oxide (Al_2O_3)	3.41	4.64
Iron(III) Oxide (Fe_2O_3)	3.41	8.64
Calcium Oxide (CaO)	62.28	5.91
Magnesium Oxide (MgO)	0.56	2.44
Sodium Oxide (Na_2O)	0.06	0.07
Potassium Oxide (K_2O)	0.82	5.50
Sulphur Trioxide (SO_3)	4.10	0.61
Loss of Ignition (LOI)	1.2	5

Source: Idris, et al (2016)

The fine pozzolanic material of Palm Oil Fuel Ash (POFA) gives away more homogenous densely packed microstructure (Munir, et al., 2015). Thus, it helps to reduce the micropores in the concrete. According to Sumadi & Hussin, (1995), the permeability of water into the concrete is decreased due to the formation of the secondary gel (C-S-H) which obtained from the hydration process through pozzolanic activity.

2.3.2 Palm Oil Clinker

Palm Oil Clinker (POC) is a solid waste material that will be used as cement replacement material. Generally, POC is known as a porous, big chunk and blackish-grey colour solid material. POC is collected from palm oil factory from the process of incineration of the palm oil shell and fibre (Kanadasan & Razak, 2015). Since the production of POC is increasing every year, the alternative way to make it as supplementary material in concrete can helps to reduce the problems regarding improper disposal of palm oil waste.

The sustainable environment can be obtained through the method of replacing a few percentages of palm oil clinker in concrete mix proportion. At the same time, the issues regarding improper disposal of palm oil waste can be reduced besides the percentage of emission of carbon dioxide release to the environment through cement processing decreasing.

Recently, most of palm oil waste is dumped to an open space or landfill sites. Some palm oil factory decided not to dispose all the clinkers instead of by taking an alternative way to reuse them as a cover for potholes on the roads within the plantation areas (Hashim, et al., 2017).

According to Hashim, et al., (2017), the chemical composition in POC may vary due to some factors such as feeding ratio in a boiler, the burning condition of the boiler and the geological condition of the respective area where the palm oil was grown. For instance, every batch of palm oil clinker produced by palm oil factory relatively does not produce the same percentage of chemical composition. The amount of silicon dioxide (SiO_2) might be an increase or decrease due to the geological factors. The presence of silica in POCP helps in enhancing the pozzolanic reaction to occur in the mortar since it can be converted from non-cement properties to a good cementing properties. Table 2.6 depicts the chemical composition of POC generally.

Table 2.6 Chemical composition of OPC and POCP

Parameter	Percentage Composition of OPC (%)	Percentage Composition of POCP (%)
CaO	64.00	6.37
SiO_2	20.29	59.90
SO_3	2.61	0.39
Fe_2O_3	2.94	6.93
Al_2O_3	5.37	3.89
MgO	3.13	3.30
P_2O_5	0.07	3.47
K_2O	0.17	15.10
TiO_2	0.12	0.29
Mn_2O_3	0.12	-
Na_2O	0.24	-
Others	0.94	0.36
LOI	1.40	1.89

Source: Ibrahim, & Razak, (2016)

A previous study conducted by Kanadasan & Razak, (2015), POC is used as a binder material to replace cement. The study conducted directly mixed with 0% to 50%

replacement of POCP without conducting a pre-treatment process. Thus, it is found that the most optimum percentage replacement of POCP is 20% of cement.

2.4 Properties of Concrete Containing Palm Oil Clinker

In every research that has been conducted, there is some parameter of observation that is aimed to be achieved. In the construction industry, some properties of concrete need to investigate, analyze and well-known by the engineer. Testing can be categorized into fresh concrete testing and harden mortar testing. The properties that are important include the compressive strength, porosity, durability, flexural behaviour test, slump test, and others. Each of the testings that conducted is purposely to make sure good quality and performance of the concrete for future development.

2.4.1 Compressive Strength

Compressive strength testing is the main testing that is very important and usually is the most common performance measure used by the engineer in designing the building and other structures. Basically, elements in pozzolan that make the concrete stronger are in the presence of a high percentage of Silica Dioxide (SiO_2) element. Partial replacement of OPC will obviously affect the strength of the concrete. A previous study that has been conducted shows that Palm Oil Clinker (POC) is one of waste that used as cement and aggregate replacing material.

According to Kanadasan & Razak (2015), Palm Oil Clinker (POC) able to achieve compressive strength with about 38.9 MPa at 28 days with 30% replacement. The nature of pozzolans stated that pozzolanic activity will occur slowly at the early stage of curing. Generally, the compressive strength of POC will be achieved to its maximum strength as the day of curing increases. Besides, replacing method can help to save the environment from pollution and leads to a sustainable environment. Figure 2.3 shows the compressive strength attained by the previous researcher. However, at a higher percentage of replacement unable to make the concrete strength increase.

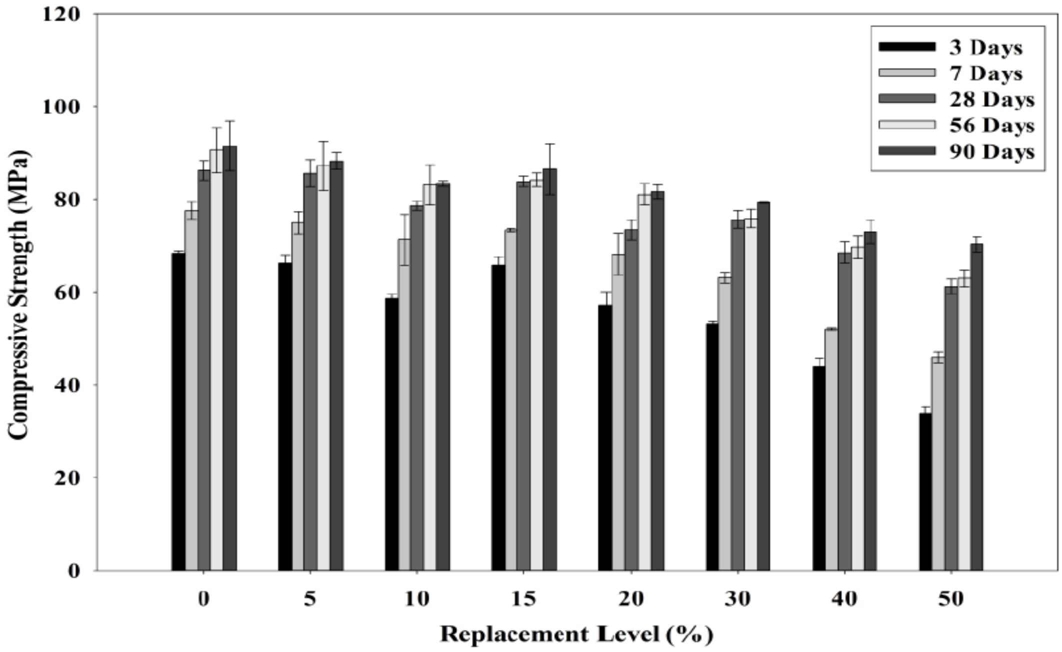

Figure 2.3 Relationship between replacement level and compressive strength

Source: Kanadasan & Razak (2015)

The early strength of the concrete is low due to the highly substituted cement with inert POC powder. Thus, the higher the percentage of replacement, the later the maximum strength will be achieved. Concrete strength development formed from the reaction between the portlandite, $Ca(OH)_2$ with SiO_2 of palm oil clinker forming C-S-H gel.

2.4.2 Porosity

Porosity testing is conducted to determine the blending effect between the cement particles and pozzolan that will act as the replacing agent in the mortar either in form of powder, fine or coarse aggregate. Determination the level of the porousness of the mortar or concrete can affect the concrete strength simultaneously. Theoretically, as the porosity decrease, the compressive strength will be increase.

Consequently, porosity is correlated with the compressive strength of concrete. The availability of a large number of pores may induce the absorption of water into the concrete and at the same time reduce the concrete strength. Poor arrangement of particles due to differences in size of Palm Oil Clinker Powder (POCP) and Ordinary Portland Cement (OPC) might contribute to the formation of pores in the concrete and affect the blending properties in the concrete (Kanadasan & Razak, 2015). Good interlocking bond is important in order to make sure the strength of concrete is improved.

The pozzolanic reaction that occurs in the concrete form an amorphous gel called calcium silicate hydrate (C-S-H). The formation of C-S-H gel in the concrete helps to make the concrete denser as the particles will fill up the voids that present in the concrete. Poor packing between cement and POC due to different in size and shape contribute to strength loss. Thus, the higher the percentage replacement, the lesser the voids in the concrete.

2.5 Summary of Literature Review

In the previous study conducted by Kanadasan & Razak, (2015), the research is aimed to investigate the Palm Oil Clinker Powder (POCP) as a binder material to replace cement. Simultaneously, the researcher carried out the study to assess the environmental impact of introducing palm oil clinker powder as cement replacement material. In regard to compressive strength, replacement of 50% of POCP specimen managed to produce almost 70% strength of control specimens. At the same time, replacement of high percentage of POCP able to make the concrete lighter than control specimen thus it reduces the total loading distributed on the structure. Besides, replacement of POC as an aggregate replacement in concrete was used to produced pervious concrete (Ibrahim, & Razak, 2016). The results show by the pervious POC concrete that the higher the percentage of replacement, the weaker the compressive strength attained by the concrete due to the porous structure of the POC. Replacing 65% of POC in concrete gave the maximum loss to the concrete thus, the most optimum percentage replacement was at 25%.

Most of the researcher concluded that by replacing the higher amount of POC in concrete either in form of cement or aggregate unable to exceed the maximum strength of the conventional sample. A few methods in extracting a high amount of silica such as thermal process and the mechanical process has been conducted previously. From the method, it shows that by heating the pozzolan at a certain temperature and grinding the pozzolan into smaller size helps to accelerate the pozzolanic reaction in the mortar. Apart from that, by conducting a chemical pre-treatment analysis also helps to enhance the chemical reaction of SiO_2 and $Ca(OH)_2$ in the mortar consecutively.

CHAPTER 3

METHODOLOGY

3.1 General

This chapter will be explained about the method to carry out the study on the process for replacing Ordinary Portland Cement (OPC) partially with the solid waste material, Palm Oil Clinker. Palm Oil Clinker (POC) is one of Malaysia biomass waste material that had not been used for specific purpose. It is part of the non-combustible residue of combustion in a furnace or incinerator where the clinkers fall by themselves into the bottom hopper of a coal-burning furnace and are cooled. Eventually, the study will be conducted on how to process the POC into a reactive material which able to convert POC from non-cementing properties to good cementing properties through the hydration process. Thus, chemical pre-treatment is conducted to remove heavy metals and undesirable material in the ash. Hydrochloric acid (HCl) is used as leaching agent to pre-treat the POCP. An optimum parameter of HCl is obtained and the mixing and casting process is conducted. Lastly, the compressive strength and porosity testing were carried out in order to determine the harden mortar properties. Figure 3.1 shows the flowchart of POC replacement in the mortar mixture

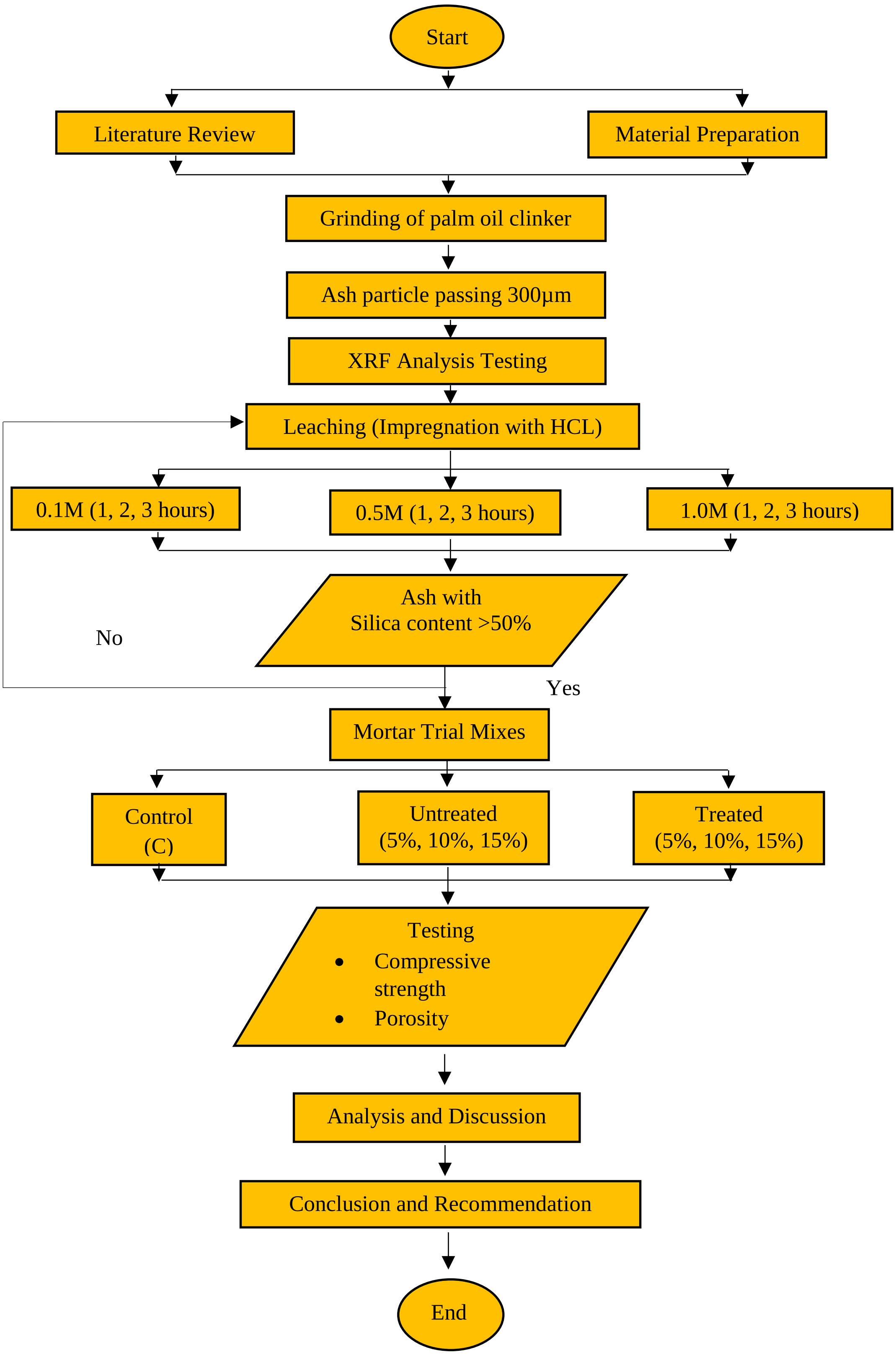

Figure 3.1 The flowchart of the process of POC replacement in mortar specimens

3.2 Experimental Detail

The process started by collecting POC from an industrial factory located at Felda Lepar Hilir, Gambang. The palm oil clinker was ground in a ball mill by using Los Angeles Machine for 5000 rotation per minute. Then, the ash was sieve passing through 300 µm size in order to obtain finer ash for the replacement process. A few stages of pre-treatment is conducted in order to remove all the undesirable elements (heavy metal) that might give hazardous effect to the concrete. Leaching method is conducted to remove the elements that might affect concrete integrity. Throughout the leaching process, hydrochloric acid (HCl) is used with three different molarity of 0.1M, 0.5M, and 1.0M. Each molarity of HCl was observed for 1, 2 and 3 hours to determine the difference of percentage for silica dioxide (SiO_2) present in the palm oil clinker ash. Among the three molarity, the most optimum parameter is chosen to be selected for a variable in the study. X-Ray Fluorescence (XRF) test was conducted to analyse the phase chemistry and oxide composition of clinkers in order to compare the ash-based clinker with commercial Portland cement clinker. From the test, the palm oil clinker should achieve the results for silica content > 50%. Mortar trial mixes are conducted once after the results are obtained.

Compressive strength and porosity testing were conducted for the hardened mortar. This is to determine the level of strength and permeability of water that able to penetrate for each per cent (5%, 10%, and 15%) replacement of cement with palm oil clinker powder for both treated and untreated ash. The data is collected and analyzed thus the objective of the study can be achieved. From Figure 3.1, it shows that the overview for the process of producing palm oil clinker ash as cement replacement element in the mortar mixture.

The reliability of instruments used is important in order to obtain a correct sample or data. There are two stages of the process conducted which were pre-treated palm oil clinker ash stage and hardened mortar stage. The tests conducted based on standard, testing age, specimen size and number of the specimen as shown in table 3.1. The tests that were conducted in pre-treated palm oil clinker ash stage is X-ray Fluorescence (XRF), while, a test that was conducted on hardened mortar stage was compressive strength test and porosity and permeability testing.

Table 3.1 The list of experimental detail of the study

Stage	Test name	Standard	Testing age	Specimen size	Number of specimens	Unit
Stage 1: Pre-treated clinker bottom ash	X-ray Fluorescence (XRF)	Operating Procedure	Min 24 hours	Powder	1 per batch	%
Stage 2 : Hardened Mortar	Compressive strength	ASTM C109 EN 196-1	7, 28, 56 days	50mm cube	3 per testing	MPa
	Porosity and permeability	ASTM C373 – 88 (2006)	7 and 28 days	50mm cube	3 per testing	%

3.3 Materials

Research materials and instruments are the main bodies in conducting the study. The materials that are used for this research is Ordinary Portland Cement (OPC), Palm Oil Clinker (POC), sand and water. While the chemical substance that used during the leaching process is hydrochloric acid (HCl). Figure 3.2 shows the main materials used in the mixing process.

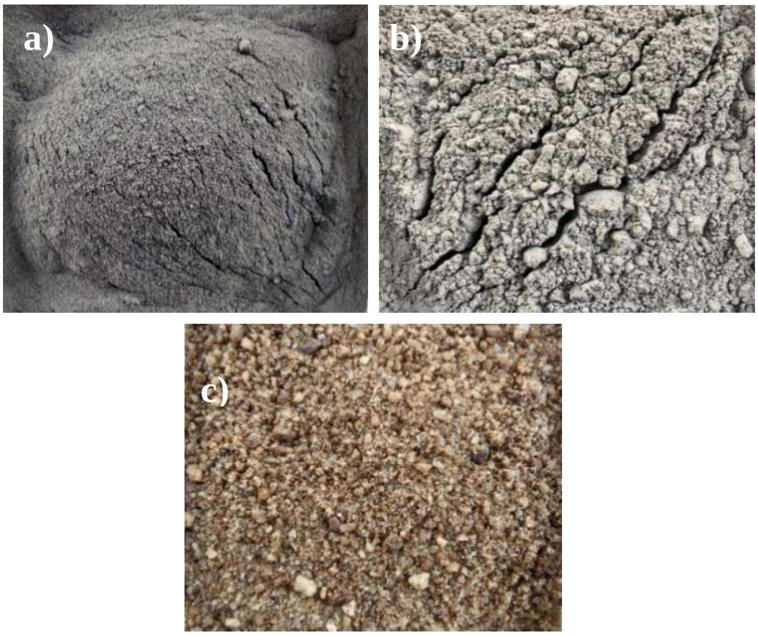

Figure 3.2 Materials used for the mortar mixture; (a) Palm Oil Clinker Powder; (b) Ordinary Portland cement; (c) Sand

3.3.1 Ordinary Portland Cement

Ordinary Portland Cement (OPC) is the main element in the concrete. In this study, a few percentages of cement replacement was used in order to reduce the utilization of cement in the construction industry. The cement was sieved by using the size of 425 μm to make it finer and more efficient. Finer cement able to gain strength faster compared to the one that contains coarser cement will smaller surface area. Besides, new cement is used in this study since old and poor quality cement would reduce the concrete strength. Table 3.2 shows the properties of Ordinary Portland Cement (OPC).

Table 3.2 The properties of Ordinary Portland Cement (OPC)

Tests	**Units**	**Specification MS EN 197-1:2014 CEM I 42.5N**	**Test Results**
		Chemical Composition	
Insoluble Residue	%	≤ 5.0	0.4
Loss On Ignition (LOI)	%	≤ 5.0	3.2
Sulphate Content (SO3)	%	≤ 3.5	2.7
Chloride (Cl-)	%	≤ 0.10	0.02
		Physical Properties	
Setting Time (Initial)	Mins	≥ 60	130
Soundness	Mm	≤ 10	1.0
Compressive Strength			
(Mortar Prism) : 2 days	MPa	≥ 10	29.7
(1:3:0.5) : 28 days	MPa	≥ 42.5; ≤ 62.5	48.9

Source: Cement, (2018)

3.3.2 Sand

Another element that used in the research is sand. Throughout the mixing process, the amount of sand used is fixed. In order to reduce the void presence in the mortar, the smaller size of sand is recommended. The sand is sieved, passing through 4.00 mm size, then it is left dry in the oven to remove excess moisture content in the sand. The sand is left cooled before it can be used for the mixing process. Figure 3.3 shows the sieve analysis graph for fine aggregate that has been conducted.

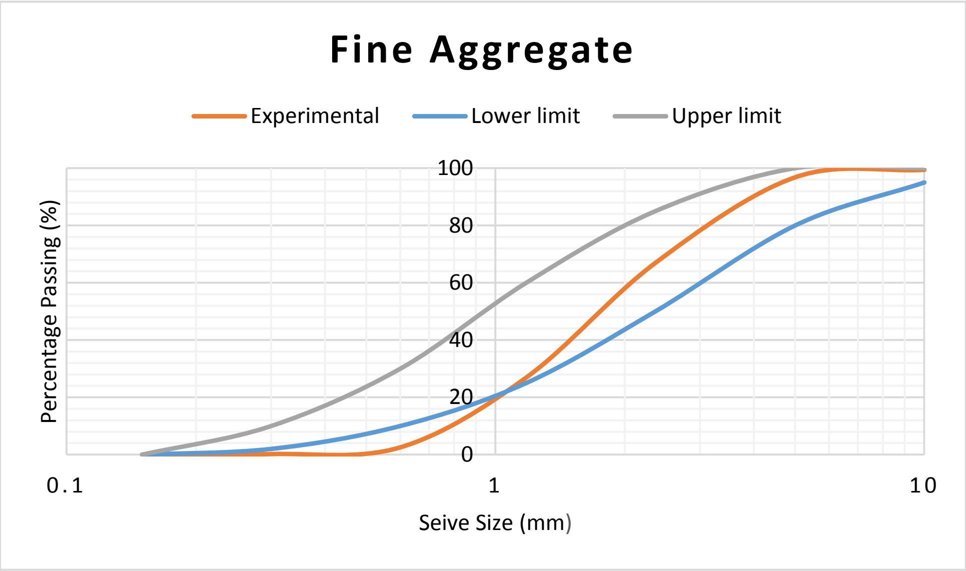

Figure 3.3 Analysis graph of fine aggregate

3.3.3 Palm Oil Clinker

Palm Oil Clinker is the main materials that will be used for the replacement process. Palm Oil Clinker is a solid waste material collected from industrial palm oil factory located at Felda Lepar Hilir. Palm Oil Clinker was undergone a few processes in producing Palm Oil Clinker Powder (POCP). The first step was grinding by using Los Angeles Machine (LA Machine) with 5000 rotation per minutes. Then, ground POC is sieved passing through a mesh size of 300 µm and lastly, it turned out into a powder form for the replacement material as shown in Figure 3.4.

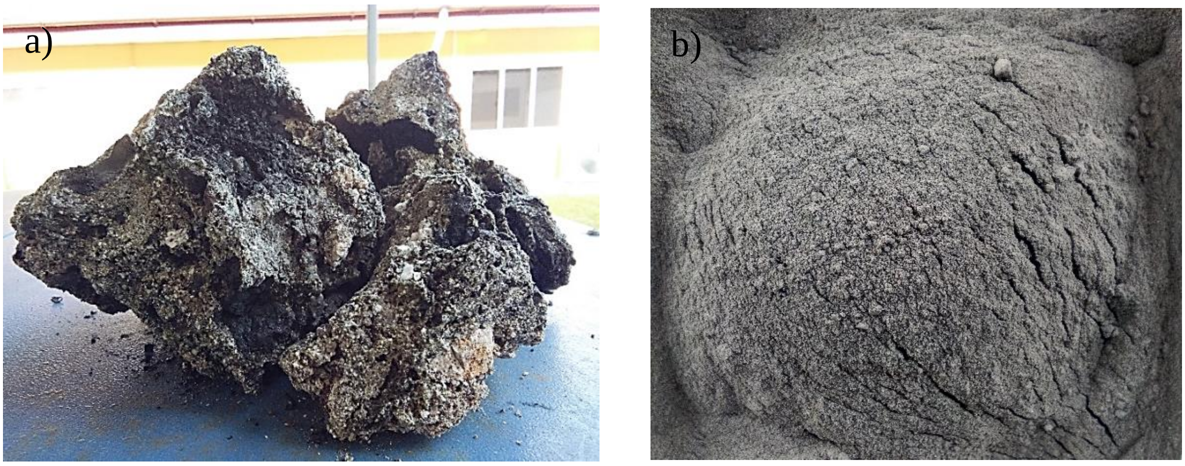

Figure 3.4 (a) Large piece of clinker from palm oil mill; (b) Palm Oil Clinker Powder

3.3.4 Water

Quality of water for mixing concrete is very important. Tap water is used for the mixing process. Improper chosen of water might affect the concrete performance includes its strength and durability. The chemical composition present in the water may participate in the chemical reactions and thus affect the setting, hardening and strength development of concrete (Kucche, et al., 2015). Pure water can help in dissolving the lime and alumina from the cement more effectively (Kucche, et al., 2015).

3.3.5 Hydrochloric Acid

Hydrochloric acid (HCl) is corrosive acid used for the pre-treatment of palm oil clinker powder through a leaching process. Three different molarity of HCl (0.1M, 0.5M and 1.0M) were used to conduct the process. Among the three, the most optimum molarity is chosen to pre-treat the POCP as it will be determined through the data obtained from the XRF analysis.

3.4 Preparation of Material

Palm Oil Clinker is the main materials used in this study as to be used for partial replacement material in a mortar. It is collected from a palm oil factory located at Felda Lepar Hilir, Gambang, Pahang. The palm oil clinker was then brought to the Concrete Lab for grinding purposes before it is added into the mortar mixture. POC is ground using Los Angeles (LA) Machine with 5000 rotation per minute. Then, the ground POC is sieved passing through 300 µm mesh size. Next, the Palm Oil Clinker Powder (POCP) is sent to the central lab to analyse its chemical oxide composition. The ash is then ready to be used for the pre-treatment process where three different molarity of hydrochloric acid with 0.1 M, 0.5 M and 1.0 M were used to conduct the process for 1 hour to 3 hours each. Among the three, the most optimum molarity is chosen to pre-treat the POCP which determined through the XRF analysis.

3.5 Pre-treatment of Palm Oil Clinker Powder

Pre-treatment of palm oil clinker powder is conducted to remove undesirable materials that presence in the specimen. Besides, this pre-treatment process helps to extract a high amount of silica from the palm oil clinker powder which indicates the main element needed in order to enhance the testing purposes.

All samples are prepared and the amount of palm oil clinker ash used for one pre-treatment is 100 grams. Hydrochloric acid is the leaching agent that will be used in the pre-treatment process and the volume of hydrochloric acid needed to treat palm oil clinker powder is 8.28 ml. Thus, every 100 g of palm oil clinker powder will consume 8.28 ml of 0.1 M hydrochloric acid with dilution 1000ml of distilled water. The detail calculation to obtain the volume of acid used for pre- treatment is shown in Appendix A.

Firstly, 100 gram of palm oil clinker powder is weighed and placed into the 1000 ml size of the beaker. 1000 ml dilution of 0.1M hydrochloric acid is filled into the beaker together with the magnetic stirrer. Then, it is placed on a hot plate for the heating process. The time taken is started when the temperature of the solution begins to increase in the range 80-90 ^{o}C. It is important to make sure that the temperature of the solution is maintained throughout the 1-hour process. After 1 hour, the beaker is left cooled for 15 minutes in the fume chamber. Then, the solution is drained out, leaving the ashes in the beaker. The ashes are then rinsed three times with distilled water in order to make it free from the acid solution containing heavy metals. Lastly, the ashes are dried in the oven with a temperature of 100 ^{o}C for 24 hours. Figure 3.5 below shows the dilution of 0.1 M hydrochloric acid with 1000 ml distilled water and the ash solution during the heating process.

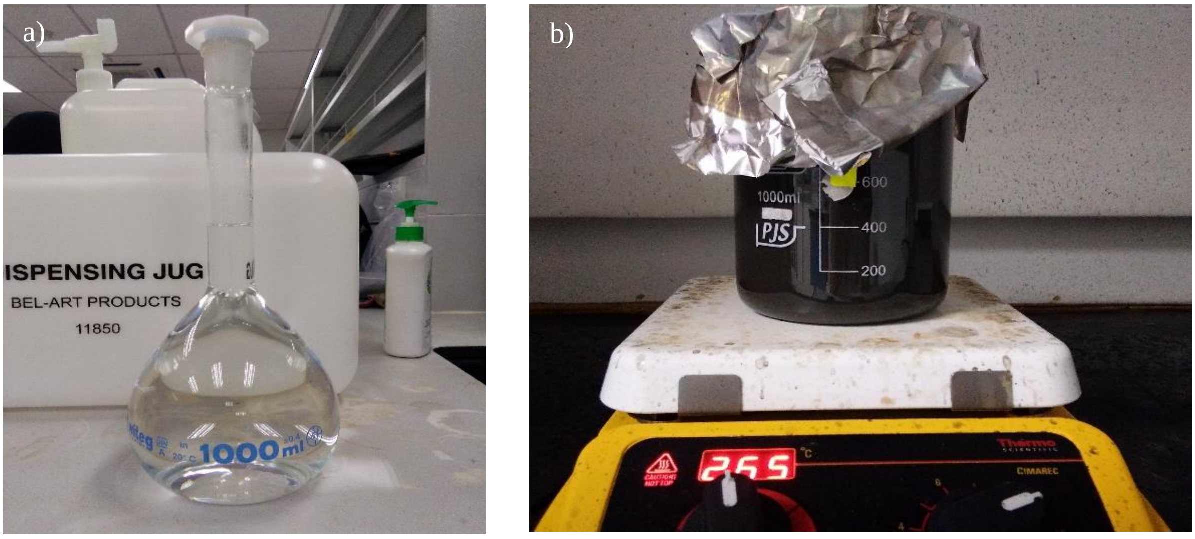

Figure 3.5 (a) Dilution of 0.1M hydrochloric acid with 1000 ml distilled water; (b) Ash solution during the heating process

3.6 Preparation of Mortar Specimen

Table 3.3 below shows the mix proportion needed for each batch of mixing process based on the percentage of cement replacement with palm oil clinker ash. Detail calculation of each sample is shown in Appendix B.

Table 3.3 Detail of Mix Proportion

Types	Code	Percentage of Replacement (%)	POCP (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)
Control	C	-		7200	5040	26640
Treated	T5	5	360	6840	5040	26640
	T10	10	720	6480	5040	26640
	T15	15	1080	6120	5040	26640
Untreated	T5	5	360	6840	5040	26640
	T10	10	720	6480	5040	26640
	T15	15	1080	6120	5040	26640

The mixing steps will follow the above requirement. Casting steps are conducted right after the mixing paste has been properly mixed. Firstly, the surface of each mould must be cleaned from any debris before oil is applied. Then, mortar paste is filled in each of the moulds. The mould is then vibrated on the vibrating table to make sure proper compaction is applied to the paste in the mould. Next, the cube mould is left setting for 24 hours. Curing is done after the demoulding process and the cube will be immersed in the large basin or container filled with water. The cube is left cured for a certain period of time for 3, 7, 28 and 56 days until it is taken out for the testing purposes.

3.7 Compressive Strength

Compressive strength is conducted by using a compression machine. Each of the cured cubes mortar with a similar size (50 mm x 50 mm x 50 mm) undergo compressive strength testing for 3, 7, 28 and 56 days. 3 cubes are tested for each day in order to obtain its average value. The data obtained are tabulated as shown in Appendix D and Appendix E. The process is conducted based on ASTM C1109 EN 196-1 standard.

3.8 Porosity

Porosity method is conducted based on ASTM C373 – 88 (2006) for 7 and 28 days cured cube specimen. The desiccator is used to allow the movement of the water into the pore of mortar cube and 3 cured mortar are used for each testing. Firstly, mortar cubes are taken out from the curing basin, dried by using tissues and weight. Then, the mortar cubes are oven dried for 24 hours with 100 ^{o}C of temperature. After oven drying, the mortar cubes is weight and left in a bucket filled with water for 48 hours. At an interval of 24 hours of immersion, the weight of mortar cubes is taken. After 48 hours, the mortar cubes are placed in the desiccator for 5 hours as shown in figure 3.6. The desiccator is switched off after 5 hours and the mortar cubes are left for 24 hours in it. Next, the cubes are taken out from the desiccator and weight for saturated mass (M) and buoyancy (S). The reading of weight is taken and the average value is calculated and tabulated as shown in Appendix F. The formula used is as followed:

$$P = \frac{(M-D)}{(M-S)}\ X\ 100 \tag{3.1}$$

where P is the apparent porosity, D is the dry mass. M is the saturated mass and S is suspended in water.

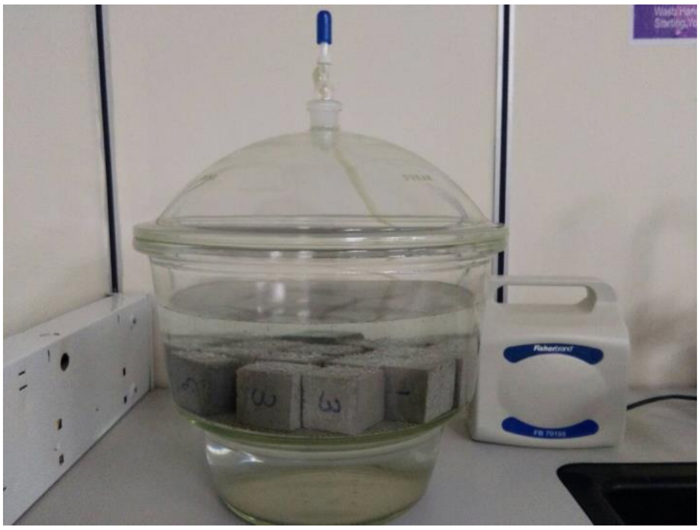

Figure 3.6 Cubes are placed in a desiccator for 5 hours

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this research, palm oil clinker powder (POCP) is used as a partial cement replacement material in concrete. Initially, X-Ray Fluorescence is conducted to determine the chemical oxide composition of POCP. The performance of hardened concrete is identified and determined based on two testing which is compressive strength testing for 3, 7, 28 and 56 days and porosity testing for 7 and 28 days with the percentage replacement of 5%, 10% and 15% treated and untreated ash respectively.

4.2 Chemical Analysis

Chemical Analysis is conducted to determine the chemical oxide composition of palm oil clinker ash before and after pre-treatment process. Chemical analysis is vital to determine its pozzolanic reactivity of the pozzolan. Pozzolan basically contains a higher amount of Silicon Dioxide (SiO_2) and a lower amount of Calcium Oxide (CaO) as compared to Ordinary Portland Cement (OPC). Palm oil clinker ash that presents in the mortar will undergo hydration process forming calcium-silicate-hydrate (C-S-H) gel which could fill the voids within the pores in the mortar thus increase in its compressive strength and reduce its porosity consecutively. In this research, X-Ray Fluorescence (XRF) testing is conducted and Table 4.1 shows the oxide composition of POC powder before and after pre-treatment process respectively.

Table 4.1 Chemical composition of POC powder before and after pre-treatment

No	Parameter	Before pre-treatment	After pre-treatment	Unit
1.	Silicon Dioxide (SiO_2)	55.39	60.23	%
2.	Potassium Oxide (K_2O)	17.70	14.84	%
3.	Iron Oxide (FeO_3)	10.81	9.13	%
4.	Calcium Oxide (CaO)	7.05	4.59	%
5.	Phosphorus Pentoxide (P_2O_5)	3.97	2.64	%
6.	Aluminium Oxide (Al_2O_3)	2.18	2.14	%
7.	Magnesium Oxide (MgO)	2.00	1.58	%
8.	Titanium Dioxide (TiO_2)	0.31	0.33	%
9.	Sulphur Trioxide (SO_3)	0.19	0.12	%
10.	Manganese (II) Oxide (MnO)	0.16	0.13	%
11.	Zirconium Dioxide (ZrO_2)	0.07	0.08	%
12.	Copper Oxide (CuO)	0.06	0.05	%
13.	Rubidium Oxide (Rb_2O)	0.05	0.05	%
14.	Strontium Oxide (SrO)	0.03	0.03	%
15.	Zinc Oxide (ZnO)	0.02	-	%
16.	Nickel Oxide (NiO)	81	-	ppm
17.	Chlorine	-	4.03	%
18.	Chromium (III) Oxide (Cr_2O_3)	-	0.02	%

Obviously, the major element to be focused on is Silica Dioxide (SiO_2). From the results, it is observed that the percentage of SiO_2 is increased from 55.39% to 60.23% after the pre-treatment process. Pozzolan is materials which contain active silica (SiO_2) and is not cementitious by itself, but, a pozzolanic reaction of SiO_2 with portlandite forming C-S-H gel will improve the mechanical strength of the mortar. The chemical pre-treatment process had successfully drained out some of the cation elements in the ash through its reaction with the hydrochloric acid (HCl). Thus, the results shows that the leaching process had affect the internal structure of the ash which finally produced a smaller size of pozzolan with bigger surface area.

4.3 Compressive Strength

Figure 4.1 below illustrates the effect of the percentage of POC powder replacement towards compressive strength for treated mortar as compared to the control samples.

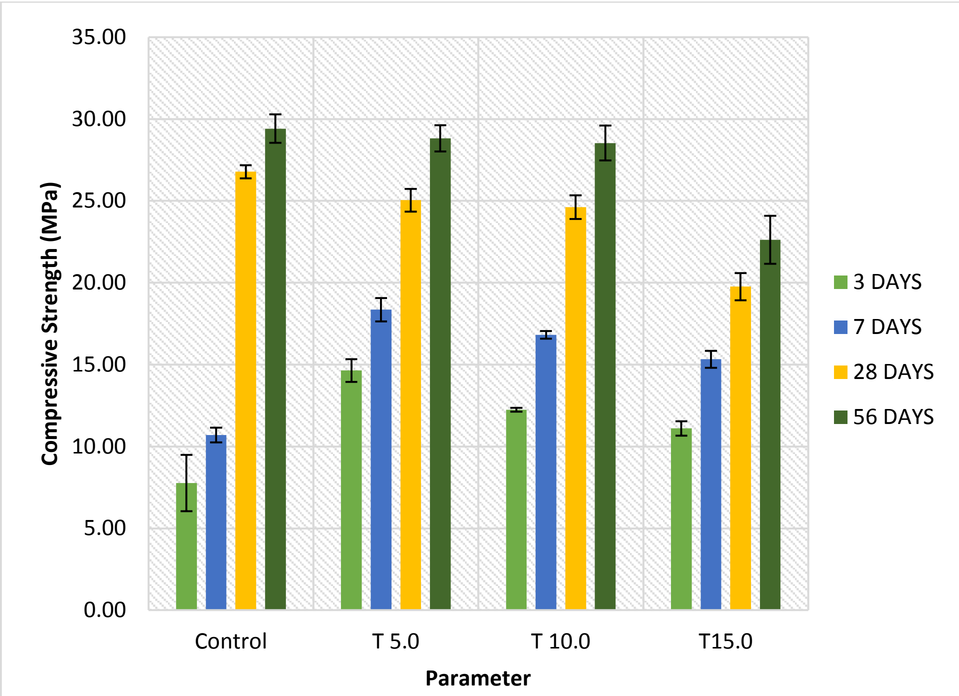

Figure 4.1 Compressive strength against the percentage of treated POCP replacement

Overall, the results of the compressive strength are taken up to 56 days. By comparing the maximum strength of T5.0, it shows that the strength gained was slightly lower than the control specimen. This is due to the pre-treatment process that has drained out deleterious material from the ash that gives effect to the performance of the mortar. (Embong, et al., 2015). However, replacement of 5% treated POC powder mixture able to give a maximum strength value of about 98% of control specimen. At the early stages, it is observed that the pozzolanic reaction for T5, T10 and T15 is faster as compared to the control specimen. The reaction starts to slow down at day 28 up to day 56 causing the maximum compressive strength attained the highest by the control samples. More amorphous silica forming the C-S-H bond at the early days making the mortar stronger and denser. Despite, a previous study finds out that POC powder only lowered the concrete strength by 13% as compared to the control specimens (Ahmmad, et al., 2017).

In short, the optimum cement replacement level of POC powder is attained by T5.0, proved by the statistical data analysis. Since the null hypothesis stated that there was no statistical significance between 2 groups, the analysis results failed to reject the null hypothesis as indicated by: t_{stat} (-0.479) < t_{crit} (2.57) and P (0.83) > α (0.05) as shown in Appendix C-2. Therefore, T5.0 can be used as an alternative source for cement replacement material.

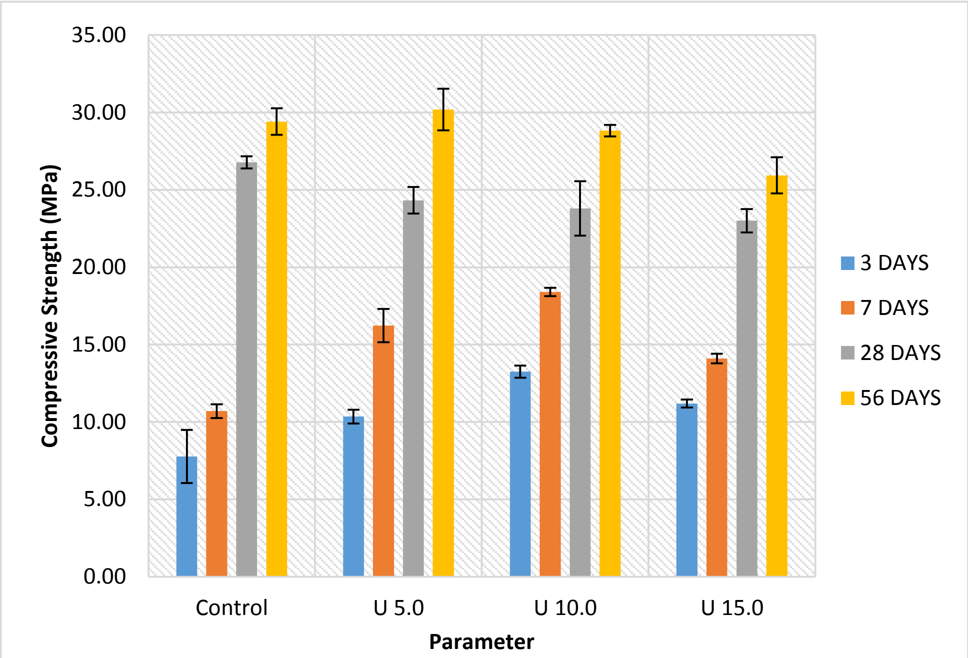

Figure 4.2 Compressive strength against the percentage of untreated POCP replacement

The major trend in Figure 4.2 is shown by U5.0 with the maximum compressive strength of 30.19 MPa exceed the control results with 29.41 MPa. This is due to the pozzolanic reaction that takes place in the concrete converting silica-rich precursor with no cementing properties to calcium silicate with good cementing properties. The pattern of strength gained by the untreated POC is slightly the same as the treated sample where the pozzolanic reaction is more effective on day 3 and day 7 as compared to the control samples. A higher percentage of replacement of POCP up to 15% unable to exceed the strength attained by control specimen due to the dilution effect as the POC powder is replaced. The higher the percentage replacement, the slower the pozzolanic reaction took place in the mortar forming a strong C-S-H bond. In brief, poor packing and the interlocking bond between cement and POC powder contribute to strength loss. In addition, POC has a flaky and irregular shape which affect the bond with the cement paste. From the results obtained, replacement of 15% POC powder gave a strength value of about 88% of the control samples.

By referring to the statistical data analysis (Appendix C-1), the replacement of U5.0 shows no significance difference with the control specimen where the t_{stat} (-0.229) < t_{crit} (2.45) and P (0.83) > α (0.05). Despite, strength gain relatively at 28 days and later must be noticeable in the trend giving higher values compared to the control samples.

4.4 Porosity

Porosity testing is conducted on day 7 and 28 of the curing days. Figure 4.3 below shows the average result porosity of mortar with different percentage replacement for control, treated and untreated samples.

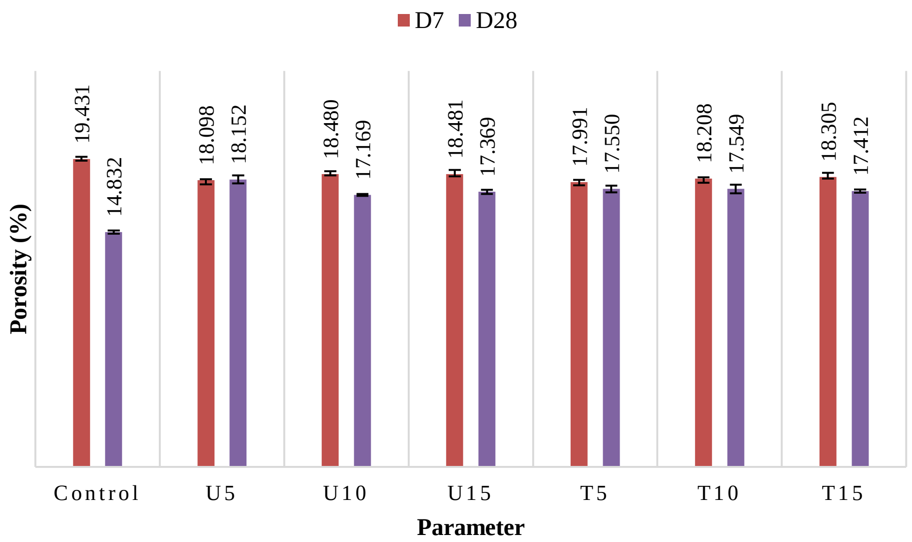

Figure 4.3 The average results of the porosity of mortar with different parameters

The purpose of the porosity testing is to determine the internal structure of the mortar and its ability to seep in water into the mortar for both conventional mortar and the additional replacement types of mortar. According to Karim, Hashim, & Razak, (2016), the microstructure of the mortar is identified that the reaction between Calcium Hydroxide ($Ca(OH)_2$) and Silicon Dioxide (SiO_2) had formed C-S-H gel for strength development. In this research, palm oil clinker powder (POCP) is used as a partial cement replacement material. From the results in Figure 4.3, it shows that an increase in the amount of POCP in mortar up to 15% reduced its porosity on day 28. However, the porosity of mortar containing POCP unable to exceed the conventional mortar simultaneously. This is due to the irregularity of shape and size of the powder particles and thus affecting blending properties between those particles consecutively.

4.5 Correlation between Parameters

Correlation between parameters is vital in order to determine its consequences of the mortar through the testing and procedure that has been conducted. It can show whether there is a strong or poor relationship between a pair of variables which identified from the results. From there, we can simultaneously correlate the degree of a relationship through the r^2 and equation produced from the exponential graph plotted. From this study, the porosity of mortar is one of the variables can be correlated with its compressive strength and unit weight.

4.5.1 Porosity vs Compressive Strength

Figure 4.4 and figure 4.5 illustrate the correlation graph between porosity and compressive strength for untreated and treated specimen comparing with control specimen respectively. Based on the results, the average compressive strength obtained by the all mortar specimen on day 28 was from 19.76 MPa to 26.78 MPa while the porosity value was from 14.83% to 19.43%.

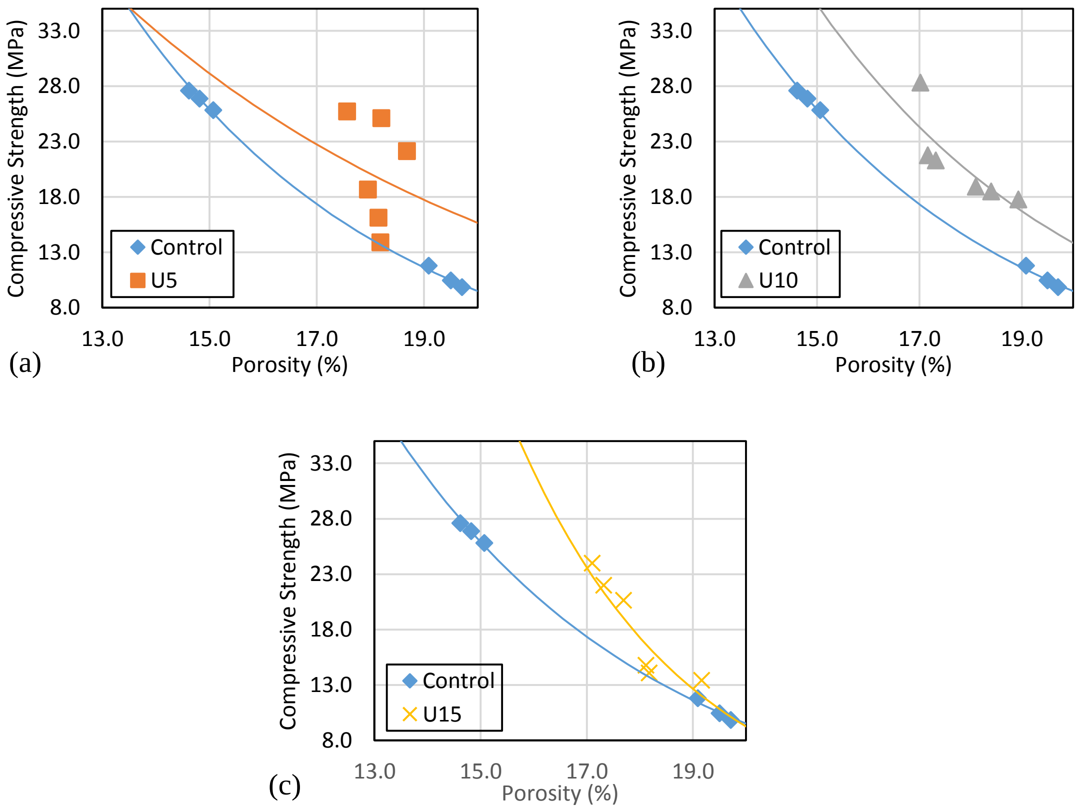

Figure 4.4 Porosity against compressive strength; (a) Control and U5 (b) Control and U10; (c) Control and U15

Table 4.2 R^2 value and equation for each parameter of untreated samples

	R^2	Equation
Control	0.9985	$fc = 523.47e^{-0.2p}$
U5	0.0331	$fc = 187.67e^{-0.124p}$
U10	0.7208	$fc = 589.44e^{-0.188p}$
U15	0.8176	$fc = 4745.8e^{-0.312p}$

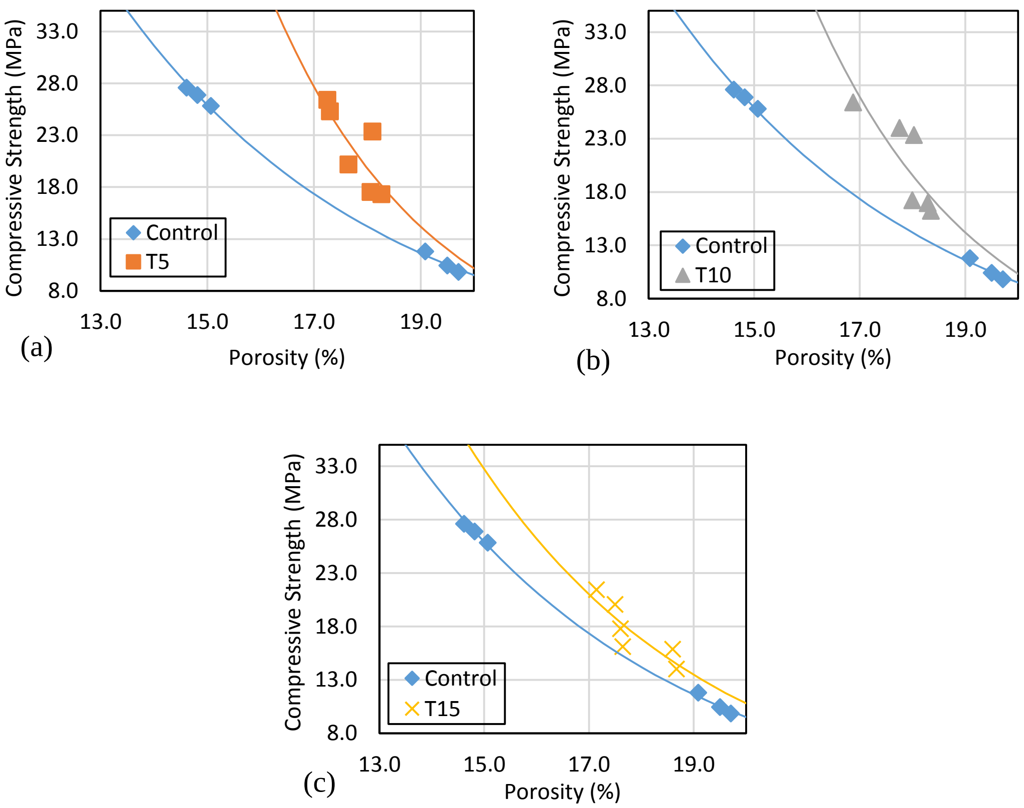

Figure 4.5 Porosity against compressive strength (a) Control and T5; (b) Control and T10; (c) Control and T15

Table 4.3 R^2 value and equation for each parameter of treated specimen

	R2	Equation
Control	0.9985	$fc = 523.47e^{-0.2p}$
T5	0.6254	$fc = 8049.9e^{-0.334p}$
T10	0.6513	$fc = 6108.2e^{-0.319p}$
T15	0.7677	$fc = 910.94e^{-0.222p}$

Table 4.2 and Table 4.3 illustrate the R^2 values and equations for each parameter of untreated and treated POC respectively. Control samples are observed to have a very good correlation with R^2 of 0.9985 which indicates a strong relationship between those variables. The compressive strength of the control sample was recorded the highest due to the less void present in the specimen. Referring to Table 4.2 and Table 4.3, a moderate correlation also shows by U15 with the R^2 of 0.8176 and T15 with R^2 of 0.7677. However, that correlation unable to exceed the R^2 obtained by the control samples. The average strength gain by substitution of U15 and T15 is low among the others with 23.01 MPa and 19.76 MPa respectively. But, within the period from 7 to 28 days, the mortar able to reduce higher percentages of porosity with about 0.89% and 1.112% respectively as compared to 5% and 10% POCP replacement. High percentage replacement of POCP able to produce denser mortar but with low strength due to the filler effect by the POCP. The POCP unable to boost up the mechanical strength of the mortar but it able to fill up the voids through the formation of the secondary gel (C-S-H) which formed from the hydration process. This also happened due to the porous structure of the POCP itself which results in low strength of mortar containing POCP.

Besides that, the low strength and high porosity of mortar are due to the availability of high amount of pore in the mortar specimen. The poor interlocking bond between cement and POC powder affect the strength formation resulting increased the coefficient of permeability. POC is flaky and irregular in shape may affect the blending effect between the cement paste and the POC itself. According to Kanadasan & Razak, (2015) different shape of particles affect the blending properties between them and significantly produced different fresh hardened and microstructure properties. As the percentage of substitution increase, the porosity will decrease and the strength will be increase consecutively.

4.5.2 Porosity vs Unit Weight

The porosity testing was carried out after 7 days and 28 days of curing. Overall, the range of unit weight obtained for all mortar specimens is 236.980 g to 260.890 g with a porosity of 14.613% to 19.499%. Figure 4.6 and Figure 4.7 show the correlation between porosity against the unit weight of the untreated sample and treated sample respectively. Particularly, increasing in the amount of POCP replacement in the mortar reduced its unit weight as compared to the control specimen. Research conducted by Karim et al., (2016) indicated that the mass of specimen decreased in curing age of 90 days due to the dehydration of calcium hydroxide ($Ca(OH)_2$) where the process took place at a temperature of 100 °C to 180 °C. It results that the micropores of POCP are reduced as it has been filled with C-S-H gel.

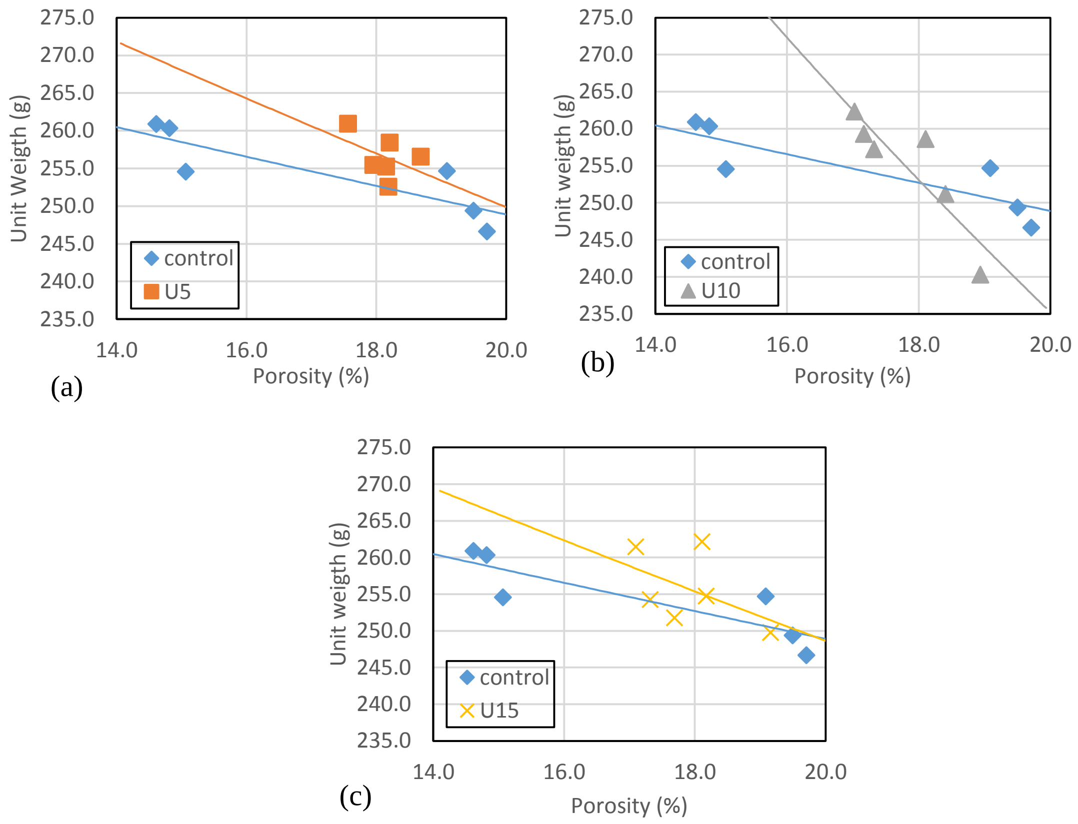

Figure 4.6 Porosity against unit weight (a) Control and U5; (b) Control and U10; (c) Control and U15

Table 4.4 R^2 value and equation for each parameter of untreated specimen

	R^2	Equation
Control	0.7301	$fc = 289.64e^{-0.008p}$
U5	0.2087	$fc = 330.88e^{-0.014p}$
U10	0.7804	$fc = 489.15e^{-0.037p}$
U15	0.2512	$fc = 325.09e^{-0.013p}$

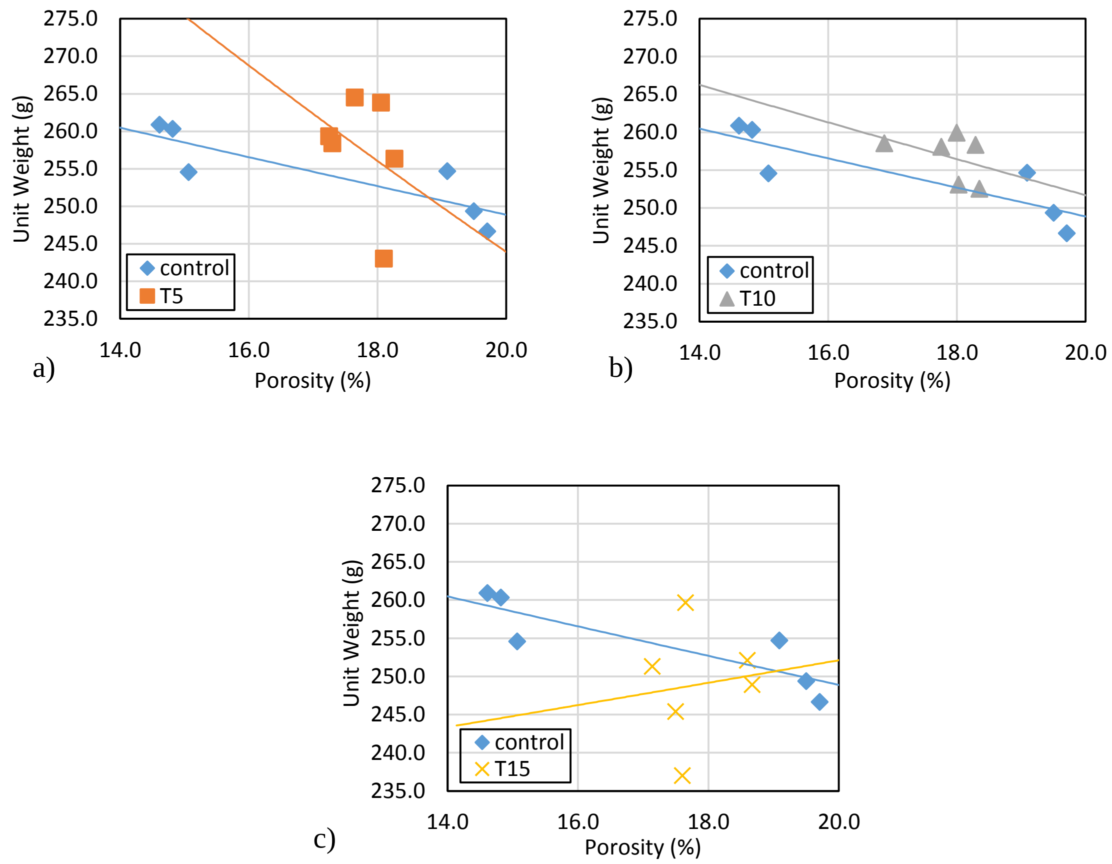

Figure 4.7 Porosity against unit weight for (a) Control and T5; (b) Control and T10; (c) Control and T15

Table 4.5 R^2 value and equation for each parameter of treated specimen

	R^2	Equation
Control	0.7301	$fc = 289.64e^{-0.008p}$
T5	0.1170	$fc = 396.09e^{-0.024p}$
T10	0.1704	$fc = 303.61e^{-0.009p}$
T15	0.0147	$fc = 224.09e^{0.0059p}$

From the results, it shows that the maximum unit weight is recorded by control samples with 0% POC powder replacement. From Table 4.4 and Table 4.5, a moderate correlation with R^2 0.7301 is obtained by control samples. Control samples are said to be a denser concrete with fewer voids due to good blending properties in the mortar. Theoretically, increasing in the percentage of POCP replacement in the mortar will make the mortar denser due to the formation of C-S-H gel. However, by the substitution, 5% to 15% of POC powder indicates a poor correlation obtained by the mortar as compared to the control samples. This is because inconsistency in the size and shape of POC powder and cement affect the interlocking bond between those particles thus forming more pores inside the concrete. The reaction between calcium hydroxide and silica took place slowly in the early age but further observation is required since the curing age will be one of the factors in forming a denser mortar. According to Ahmmad, et al., (2017), by substituting 5%, 10%, 15% and 20% of POC powder, the mortar is found to be lighter than the normal mortar. Thus, as the curing age increase, the porosity of the mortar and its unit weight will decrease respectively.

4.6 Summary of Results

Overall, the chemical pre-treatment of Palm Oil Clinker (POC) by using 0.1 M hydrochloric acid (HCl) at 1-hour has successfully extracted the amount of silica from the ash thus results in increasing the percentage of Silica Dioxide (SiO_2) up to 4.84%. Silica is one of the elements that has an ability to improve the mechanical strength of mortar where the pozzolanic reaction converts silica-rich precursor with no cementing properties to calcium silicate with good cementing properties.

As can be seen from the results, the compressive strength of treated and untreated mortar unable to exceed the maximum strength achieved by the control specimen. Nevertheless, the maximum strength achieved by the T5 and U5 show there was no significance difference between the control samples and thus showing that the null hypothesis objective is failed to be rejected as indicated by t_{stat} (-0.479) < t_{crit} two tail (2.57) and P (0.83) > α (0.05), the t_{stat} (-0.229) < t_{crit} (2.45) and P (0.83) > α (0.05) respectively.

While the porosity testing proved that an increase in the amount of POCP replacement in the mortar reduces the number of voids due to the formation of C-S-H gel. However, due to the porous structure and irregularity in size and shape of POC also contributes to a lower compressive strength of mortar as compared to the control specimen. The poor interlocking bond between the cement particles and POC particles affect the blending properties. In consequence, higher replacement of POC in mortar able to produce a lighter mortar as compared to the control mortar accordingly.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Partial substitution of solid waste materials helps to overcome the problems in agricultural and construction industries consecutively. Emission of carbon dioxide (CO_2) to the environment through the production of cement can be reduced by implementing the method of utilizing partial replacement of palm oil clinker ash into cement in mortar mixture. At the same time, a proper management of solid waste material can be maintained also significantly reduced dumping areas in disposing of the agricultural waste. From this study, it is concluded that:

1. Chemical pre-treatment proved that the percentage of silica in the ash increasing after the leaching process is conducted by using the parameter of 0.1 M hydrochloric acid at 1 hour.

2. The compressive strength of mortar is inversely proportional to the replacement level. As the percentage of replacement increase, the compressive strength gained by the mortar decrease. While the porosity of mortar decrease as the percentage of POC replacement increase.

3. The most optimum percentage replacement is treated 5% of POCP which able to produce a high compressive strength and low porosity types of mortar consecutively.

5.2 Recommendations

Although the objectives of the study are achieved, here are 3 recommendations suggested improving the results.

1. It is recommended that the Palm Oil Clinker Powder (POCP) is impregnated with different types of acid leachant in order to extract a higher percentage of silica from the ash.

2. A finer particle size of the Palm Oil Clinker Powder (POCP) helps to enhance pozzolanic reaction to occur since the nature of POC is flaky and irregular in shape which might affect the blending properties in the mortar.

3. Palm Oil Clinker is considered as a low strength pick-up pozzolan as compared to the other pozzolan. Thus, the increase in curing ages improved the mechanical strength of mortar as it shows the state of pozzolanic reaction to occur.

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APPENDIX A
DETAIL OF PRE-TREATMENT CALCULATION

Mass = 1.19 g/ml

Concentration = 37%

1. Mass of solution = 1.19 g/ml x 1000 ml
   = 1190 g

2. Mass of HCL = Concentration x Volume
   = (37/100) x 1190 g
   = 440.3 g
3. Relative Atomic Mass of HCL = 1+35.5
   = 36.5

4. Mole of HCL = Mass / Relative Atomic Mass of HCL
   = 440.3 / 36.5
   = 12.06 mol/L

   From above, M_1 = 0.1 M, M_2 = 12.06, V_1 = 500 ml

5. $M_1 V_1 = M_2 V_2$
   (0.1)(500) = (12.06)(V_2)
   V_2 = 4.14 ml

   From the calculation above, it shows that the volume of hydrochloric acid needed in order to treat palm oil clinker powder. Thus, every 50 g of palm oil clinker powder will consume 4.14 ml of 0.1 M hydrochloric acid with dilution 500ml of distilled water.

APPENDIX B
DETAILS OF MIX PROPORTION

Total cubes = 18 cubes

Volume of mould = 0.05 x 0.05 x 0.05

= 0.000125 m3

18 cubes x 0.00125 m3 = 0.00225m3

Wastage (20%) = 0.00045 m3

Total = 0.00225 m3 + 0.00045 m3

= 0.0027 m3

Water/Cement Ratio = 0.7

Cement (C) = 400 kg/m3

Water (W) = 280 kg/m3

Sand (S) = 1480 kg/m3

Total = 2160 kg/m3

APPENDIX C
STATISTICAL ANALYSIS DATA

Appendix C-1 : t-Test: Two-Sample Assuming Unequal Variances

	Control	Untreated 5%
Mean	18.6655	20.27191667
Variance	121.1529922	76.52386655
Observations	4	4
Hypothesized Mean Difference	0	
df	6	
t Stat	-0.228512668	
P(T<=t) one-tail	0.413418416	
t Critical one-tail	1.943180281	
P(T<=t) two-tail	0.826836831	
t Critical two-tail	2.446911851	

Appendix C-2 : t-Test: Two-Sample Assuming Unequal Variances

	Control	Treated 5%
Mean	18.6655	21.71383333
Variance	121.1529922	40.88937752
Observations	4	4
Hypothesized Mean Difference	0	
df	5	
t Stat	-0.478936745	
P(T<=t) one-tail	0.326097667	
t Critical one-tail	2.015048373	
P(T<=t) two-tail	0.652195335	
t Critical two-tail	2.570581836	

APPENDIX D
COMPRESSIVE STRENGTH

	No. of Sample	3 DAYS	7 DAYS	28 DAYS	56 DAYS
		Strength (MPa)	Strength (MPa)	Strength (MPa)	Strength (MPa)
Control	1	7.22	11.80	25.83	28.75
	2	4.24	10.45	27.61	27.90
	3	11.86	9.85	26.89	31.59
	Average	**7.77**	**10.70**	**26.78**	**29.41**
U 5.0	1	9.77	13.89	22.14	33.19
	2	11.48	16.12	25.72	30.19
	3	9.80	18.67	25.12	27.18
	Average	**10.35**	**16.23**	**24.33**	**30.19**
U 10.0	1	14.23	17.78	28.33	29.413
	2	12.52	18.93	21.31	28.24
	3	13.00	18.50	21.77	
	Average	**13.25**	**18.40**	**23.80**	**28.83**
U 15.0	1	10.91	13.43	20.65	24.09
	2	11.86	14.09	24.01	27.78
	3	10.80	14.78	22.01	
	Average	**11.19**	**14.10**	**23.01**	**25.93**
T 5.0	1	14.55	17.56	25.32	28.67
	2	16.24	20.19	26.43	30.67
	3	13.15	17.327	23.37	27.09
	Average	**14.64**	**18.36**	**25.04**	**28.81**
T 10.0	1	11.97	16.96	26.43	31.27
	2	12.32	16.24	24.03	27.01
	3	12.46	17.24	23.37	27.32
	Average	**12.25**	**16.81**	**24.61**	**28.53**
T15.0	1	10.22	15.87	17.79	24.945
	2	12.14	16.12	21.45	20.31
	3	10.94	14.00	20.05	
	Average	**11.10**	**15.33**	**19.76**	**22.63**

APPENDIX E
COMPRESSIVE STRENGTH RAW DATA

Control	3	266.99	7.22
		213.69	4.24
		269.73	11.86
	7	272.89	11.80
		269.79	10.45
		271.36	9.85
	28	267.39	25.833
		270.21	27.609
		264.07	26.893
	56	260.76	28.754
		270.54	27.895
		270.29	31.589
U5	3	286.76	9.77
		271.45	11.48
		277.51	9.80
	7	270.02	13.89
		273.61	16.12
		280.72	18.67
	28	272.01	22.14
		298.79	25.72
		273.1	25.12
	56	273.15	33.193
		283.53	30.186
		307.08	27.179
U10	3	281.12	14.23
		274.68	12.52
		278.97	13.00
	7	281.57	17.79
		281.16	18.93
		285.01	18.50
	28	277.75	28.325
		288.48	21.31
		282.19	21.77
	56	279.29	24.086
		277.75	27.78

U15	3	263.1	10.91
		280.81	11.86
		266.66	10.80
	7	266.55	13.43
		259.70	14.09
		268.91	14.78
	28	265.89	20.649
		291.27	24.01
		288.48	22.01
	56	264.1	24.945
		280.25	20.31
T5	3	286.69	14.55
		287.05	16.24
		275.00	13.14
	7	273.17	17.56
		284.75	20.19
		288.57	17.327
	28	285.21	25.32
		280.87	26.43
		290.09	23.37
	56	286.71	28.668
		279.89	30.673
		284.93	27.093
T10	3	269.87	11.97
		285.02	12.32
		281.18	12.46
	7	268.48	16.96
		267.28	16.24
		272.47	17.24
	28	272.75	26.43
		268.73	24.03
		280.69	23.37
	56	286.56	31.274
		291.7	27.007
		289.82	27.322

T15	3	268.47	10.22
		272.09	12.14
		275.95	10.94
	7	273.32	15.87
		272.08	16.12
		268.04	14.01
	28	280.08	17.79
		274.4	21.45
		274.51	20.05
	56	271.11	24.945
		266.88	20.31

APPENDIX F
POROSITY

CONTROL										
	CURING WEIGH	OVEN	1st SOAK	2nd SOAK	SSD C	BUOYANCY	POROSITY		STRENGTH (MPa)	
D7	**280.55**	254.68	278.74	278.96	279.37	152.75	19.50	19.43	9.48	**15.16**
	272.09	246.65	270.44	270.63	271	147.44	19.71		18.24	
	274.21	249.38	272.56	272.72	273.16	148.57	19.09		17.76	
D28	**274.45**	254.56	272.22	272.63	273.32	148.81	15.07	14.83	13.17	**12.84**
	280.81	260.89	278.62	279.02	279.63	153.14	14.82		11.89	
	280.01	260.33	277.79	278.22	278.69	153.05	14.61		13.46	

UNTREATED 5.0										
	CURING WEIGH	OVEN	1st SOAK	2nd SOAK	SSD C	BUOYANCY	POROSITY		STRENGTH (MPa)	
D7	**279.73**	255.26	277.53	277.61	278.56	150.46	18.19	18.10	16.53	**16.81**
	280.14	255.47	277.80	277.92	278.61	151.12	18.15		18.30	
	276.62	252.59	274.45	274.45	275.32	148.73	17.96		15.61	
D28	**280.29**	256.55	277.6	277.9	278.39	161.49	18.68	18.15	16.64	**17.30**
	284.05	258.42	281.19	281.54	282.14	151.86	18.21		17.96	
	285.31	260.95	282.77	283	283.61	154.61	17.57		14.15	

UTREATED 10.0										
	CURING WEIGH	OVEN	1st SOAK	2nd SOAK	SSD C	BUOYANCY	POROSITY		STRENGTH (MPa)	
D7	**282.85**	258.61	281.04	281.36	281.85	153.47	18.10	18.48	13.60	**12.84**
	263.74	240.28	262.61	262.86	263.41	141.25	18.93		12.12	
	275.44	251.18	273.86	274.21	274.73	146.76	18.40		12.80	
D28	**283.39**	259.30	281.51	281.77	281.84	151.71	17.32	17.17	17.18	**18.55**
	286.25	262.33	284.13	284.44	284.54	154.06	17.02		18.50	
	280.89	257.23	278.78	279.09	279.19	151.25	17.16		19.96	

UNTREATED 15.0										
	CURING WEIGH	OVEN	1st SOAK	2nd SOAK	SSD C	BUOYANCY	POROSITY		STRENGTH (MPa)	
D7	**278.37**	254.75	276.92	277.20	277.98	149.71	18.11	18.48	9.45	**12.50**
	288.35	262.15	286.77	287.06	287.43	155.49	19.16		12.60	
	272.94	249.77	271.45	271.72	272.27	148.46	18.17		15.44	
D28	**285.19**	261.45	283.62	283.92	284.03	153.63	17.32	17.37	17.30	**18.72**
	277.52	254.26	275.22	275.48	275.81	149.78	17.10		20.59	
	275.61	251.76	273.42	273.71	273.95	148.52	17.69		18.27	

TREATED 5.0										
	CURING WEIGH	OVEN	1st SOAK	2nd SOAK	SSD C	BUOYANCY	POROSITY		STRENGTH (MPa)	
D7	**288.46**	263.83	286.60	286.93	287.42	158.27	18.27	17.99	20.91	**18.69**
	289.04	264.51	287.24	287.60	288.2	157.01	18.06		17.16	
	279.88	256.35	277.85	278.20	278.63	152.39	17.65		17.99	
D28	**281.88**	258.41	279.77	280.1	280.52	152.34	17.25	17.55	21.80	**21.31**
	282.97	259.34	280.67	280.95	281.28	154.47	17.30		24.06	
	266.67	243.05	264.40	264.62	265.04	143.54	18.10		18.07	

TREATED 10.0										
	CURING WEIGH	OVEN	1st SOAK	2nd SOAK	SSD C	BUOYANCY	POROSITY		STRENGTH (MPa)	
D7	**282.16**	258.33	280.63	280.90	281.66	154.07	18.29	18.21	14.55	**16.49**
	275.93	252.54	274.53	274.7	275.64	149.72	18.34		17.04	
	283.82	259.97	282.2	282.49	283.37	153.32	17.99		17.87	
D28	**276.69**	253.09	274.95	275.38	275.96	149.07	18.02	17.55	14.15	**20.58**
	282.8	258.56	280.56	280.96	281.47	152.43	17.75		20.54	
	280.95	258.08	278.86	279.24	279.82	150.95	16.87		20.62	

TREATED 15.0										
	CURING WEIGH	OVEN	1st SOAK	2nd SOAK	SSD C	BUOYANCY	POROSITY		STRENGTH (MPa)	
D7	**283.7**	259.64	282.17	282.39	283.03	150.48	17.65	18.30	13.35	**14.82**
	274.09	248.92	272.01	272.35	272.91	143.91	18.60		15.61	
	277.14	252.11	275.14	275.48	276.11	147.57	18.67		15.49	
D28	**276.05**	251.29	273.58	273.87	274.05	144.73	17.60	17.41	18.10	**17.77**
	259.82	236.98	257.30	257.63	257.67	136.96	17.14		18.90	
	269.54	245.37	267.19	267.51	267.58	140.63	17.50		16.30	