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COMPRESSIVE STRENGTH OF LIGHTWEIGHT FOAMED CONCRETE USING ARTIFICIAL AGGREGATE FROM PALM OIL CLINKER

AKMAL HAKIM BIN MUHAMMAD SHA'ANI

A thesis submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Civil Engineering

Faculty of Civil Engineering and Earth Resources
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JUNE 2012

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DEDICATION

Praise to be Allah, the Lords of the Worlds

Then I dedicated this work especially to Mama and Ayah, and then to all who supported me till the end.

ACKNOWLEDGEMENT

Praise be to Allah, the Lords of the Worlds

First and foremost, thanks to god and his willingness, I have accomplished this final year project as a requirement to graduate and acquire a bachelor degree in civil engineering from University Malaysia Pahang (UMP). There are number of people without whom this achievement might not have been done, and to whom I am greatly indebted.

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ABSTRACT

Malaysia as one of the world's largest exporter of palm oil has been facing problem in disposing palm oil clinker, a by-product of palm oil mill since many years ago. Through public concerns and research efforts, the agro waste by-product materials have potential to be utilized as construction material to replace conventional sand in lightweight foamed concrete (LWC). In this study, the effectiveness of agro waste ash by-product namely palm oil clinker (POC) was developed as an alternative material to replace the sand. The effect of using different percentages of POC to LWC due to compressive strength was investigated. Five series of mix formulation of LWC with mix density of 1600kg/m^3 were prepared that comprise of 0%, 25%, 50%, 75% and 100% as sand replacement from the total weight of sand was replaced with POC. All the LWC samples are cured in air curing for different curing ages namely 7, 28 and 60 days. The result revealed that the higher compressive strength was achieved through the addition of POC. The compressive strength also improved due to increasing of curing days. It is noted that the optimal mix to produce the highest compressive strength is by replacing 75% sand with POC.

ABSTRAK

Malaysia merupakan antara pengeluar kelapa sawit terbesar didunia menghadapi masalah dalam pembuangan klinker kelapa sawit, penghasilan daripada kelapa sawit sejak beberapa tahun yang lalu. Melalui kesedaran orang ramai dan juga usaha ujikaji, pembuangan sisa ini ada potensi untuk digunakan dalam bahan pembinaan bagi menggantikan pasir di dalam konkrit ringan beronga (LWC). Dalam kajian ini, keberkesanan pengeluaran bahan buangan kelapa sawit yang dinamakan klinker kepala sawit (POC) dibangunkan sebagai bahan alternatif untuk menggantikan pasir. Pengaruh penggunaan POC dalam peratus yang berbeza untuk LWC telah dikaji. Lima siri formulasi campuran LWC dengan campuran ketumpatan 1600kg/m^3 yang telah disediakan terdiri daripada 0%, 25%, 50%, 75% dan 100% daripada berat pasir telah digantikan dengan POC. Kekuatan mampatan konkrit POFA akan diuji selepas mengalami proses pengawetan udara sehingga umur konkrit 7, 28, dan 60 hari. Keputusan kajian mendapati bahawa dengan menggantikan pasir dengan POC dapat mempengaruhi kekuatan mampatan LWC dengan ketara. Kekuatan mampatan juga meningkat kerana penigkatan hari pengawetan yang berbeza. Adalah difahamkan bahawa campuran yang optimum untuk menghasilkan kekuatan mampatan yang tertinggi adalah dengan menggantikan 75% pasir dengan POC.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Sustainable development is about pursuing economic growth without jeopardizing the environment. Sustainable development has become a key aspect in society as it is an initiative to meet the need of the present without compromising the ability for the future generations to meet their needs (Hamid, 2011). It is also a systematic approach to achieve human development in a way that it sustains the limited planetary resources. The use of waste materials as recycled products is one of the initiatives towards the sustainable development. It will reduce the total amount of pollutants and in the same time, it will reduce the total usage of the limited raw materials.

The conventional approach to the design and construction of buildings in Malaysia uses reinforced concrete, steel or timber as structural members for load transmittal to the foundation (Kamaruddin, 2001). Concrete is one of the most common construction materials and is employed in a wide variety of applications, ranging from piles to multi-storey buildings. It is one of the most economical materials of construction, being very versatile by nature and flexible in application (Somayaji, 2001).

Concrete density can be reduced in several ways, and these include using lightweight aggregates, foams, high air contents and others (Hamidah et. al., 2005). Similar to cement bricks which its materials are almost same as concrete, lightweight cement bricks can be produced with the use of foaming agent. Lightweight concrete can reduce the dead load of structure which economises the design of the structure members. With the low density of foamed concrete combined with the utilization of waste materials, the production of concrete will be more efficient.

On the other hand, palm oil industry is one of the most important economic contributors to Malaysia's treasury. As the production of crude palm oil increases, a large amount of wastes are produced. Millions of tonnes of palm oil wastes such as palm oil fibres, palm oil fuel ash and palm oil sludge are produced from the output of the crude palm oil (Shahrul, 2010). Fortunately, most of the wastes are utilized and recycled to reduce the amount of disposals that will cause environmental problems. However, palm oil clinkers are the only waste materials that did not used as recycled materials yet.

Therefore, by replacing a certain amount of sand with palm oil clinker it will lead to an efficient and sustainable cement brick product and making the palm oil industry a sustainable industry where all its waste materials are converted into beneficial recycled material. There are many attempts to replace fine aggregates in concretes which are similar to the cement bricks where the fine aggregates were partially replace with waste materials such as palm oil fuel ash, quarry dust and rice husk ash. These attempts led to a very positive result where the strength of the concrete is enhanced by the utilization of the waste materials.

In this study, palm oil clinker (POC) will be used as sand replacement in the lightweight foamed concrete and the effects of the palm oil by-products on the lightweight foamed concrete will be investigated.

1.2 PROBLEM STATEMENT

The amounts of agricultural wastes, biological resources, are increasing in developing countries due to increased agricultural activities. These agricultural wastes have remained underutilized due to lack of technology for effective use. The increasing demand for industrial raw materials and the realization that more natural resources, especially minerals, are not renewable, agricultural wastes were one of the developments of bio-wastes as a potential source of raw materials.

The use of foamed concrete or lightweight concrete has been used widely as it reduces the dead weight of a structure resulting from smaller supporting sections and foundations. Strength of foamed concrete is mainly dependent on the amount of sand. The use of recycled materials as concrete ingredients has been gaining popularity because of increasingly stringent environmental legislation. This use reduces the amount of landfill space required as the palm oil by-products acts as a sand replacement thus reducing the amount of sand required.

1.3 OBJECTIVE OF STUDY

The objectives of the study are:

a) To investigate the effectiveness of using the palm oil clinker as potential partial aggregate replacement in lightweight concrete in terms of compressive strength.
b) To determine the optimal mix of palm oil clinker in lightweight concrete.

1.4 SCOPE OF STUDY

In this study, lightweight foamed concrete (LWC) will be produced by using artificial aggregate from by-product of palm oil waste. The compressive strength of the LWC will be investigated in accordance to BS: 1881: Part 116: 1983 and will be compared to LWC without any sand replacement. The mix is design to obtain a density of 1600 kg/m^3 with cement, sand and water ratio is 2:1:1.

Before the compression test is conducted, palm oil clinker (POC) will be tested for density, specific gravity, and absorption in accordance to ASTM C 128-01 Standard Test Method. There will be 36 cubes of LWC to be prepared for the compressive test with different percentages of. The compressive strength of the cube specimens will be observed at 7, 28 and 60 days of age. The number of cubes prepared is shown in Table 1.1.

Table 1.1: Numbers of LWC specimens for Compression Test

Mix Design	Mix Proportion Cement: Sand: Water	Percentage of POC (%)	Numbers of Sample		
			7 days	28 days	60 days
1600 kg/m^3	2:1:1	0	3	3	3
		25	3	3	3
		50	3	3	3
		75	3	3	3
		100	3	3	3

1.5 SIGNIFICANCE OF STUDY

The significance of study will contribute towards the application of palm oil by-products as part of aggregate replacement hence improves the environmental properties of lightweight foamed concrete and making the palm oil industry a sustainable industry where all its waste materials are converted into beneficial recycled material. The cost lightweight foamed concrete can be reduced as it utilizes the palm oil by-products as the aggregate component in the mixture, thus reducing the amount of sands in construction.

1.6 EXPECTED OUTCOME

From this study it is expected that the outcomes are:

i. The lightweight foamed concrete with the palm oil clinkers will at least have the same strength as the normal lightweight foamed concrete so that the palm oil by-products can replace the sand entirely.

ii. The optimum mix of palm oil clinker for lightweight foamed concrete can be determined.

1.7 CONCLUSION

The lack of natural resources due to the increased of development activities has led to pursue of the sustainable development in construction where it is an industry that consumes a lot of natural minerals. The development of palm oil clinker as an artificial aggregate can help reduce the usage of sand in construction which is a scarce material that led to illegal activities of sand mining. The following chapter will study the lightweight concrete, fine aggregates and factors affecting compressive strength of concrete.

CHAPTER 2

Literature Review

2.1 INTRODUCTION

The use of lightweight aggregate concretes allows greater design flexibility and substantial cost savings, reducing dead load, allowing slender structural elements, less reinforcing steel and lower foundation costs as it offers lesser density than the conventional concrete. According to Barbosa et. al. (2011), it is also known that the reduction in the concrete density increases the thermal resistance, leading to a positive impact on the energy consumption of a building.Another obvious application of lightweight concrete is in prestressed members, particularly in larger span beams such as those used in bridge decks where the self-weight is a relatively large proportion of the total load to be carried (Dhir et al, 1984). Therefore, the application of lightweight foamed concrete in civil structures such as bridges can reduce the total cost of construction.

Palm oil industry is one of the sectors famously chosen to be developed commercially in several tropical countries located espcially in Malaysia. Basiron and Simeh (2005) forecasted that Malaysia, the current number one palm oil producer will maintain its lead position by producing 18 million tones or 42% of the world palm oil production in 2020. With the huge numbers of oil palm production, the amount of waste from the palm oil industry also significantly higher. The wastes that will be produced from oil palm oil palm production are palm oil fibre, palm oil shell and palm oil sludge. The fibres and shells is used by the palm oil mill as boiler fuel to produce steam for electricity generation. Palm oil fuel ash will be produced after the combusion of both the fibres and shells in the boiler.

2.2 OVERVIEW OF LIGHTWEIGHT FOAMED CONCRETE

Generally, lightweight foamed concrete is a mix of fine sands, cement, water and foaming agent.Lightweight foamed concrete is a specializezed product that contains more than 25% of air volume when compared to the conventional concrete and this is achieved by incorporation of foaming agent into a concrete mix (Dundee, 2005). The addition of the foaming agent lowers the density of the concrete.

Lightweight foamed concrete is a class of aerated concrete. Aerated concrete can be classified according to the methods and agents used to introduce air in the concrete. Aerated concrete can be produced by introducing air entraining agent, gas forming chemicals and foaming agents. Concrete which is aerated using foaming agent is known as lightweight foamed concrete. Foaming agents can be synthetic based or protein based.

2.2.1 History of Lightweight Foamed Concrete

Romans in the second century where 'The Pantheon' has been constructed using pumice, the most common type of aggregate used in that particular year (Samidi, 1997). Since then, the use of lightweight foamed concrete has been widely spread across other countries such as USA, United Kingdom and Sweden. In UK, 10 years ago the usage of lightweight foamed concrete has grown more rapidly than any other "special" concrete product. Lightweight foamed concrete can be defined as a type of concrete including an expanding agent in that it increases the volume of the mixture while giving adding qualities such as fallibility and lessened the dead weight (Zakaria, 1978). Lightweight foamed concrete is 87% to 23% lighter than the conventional concrete with a dry density from 300 kg/m^3 up to 1840 kg/m^3. The main specialties of lightweight foamed concrete are its low density and thermal conductivity. Its advantages included reduction of dead load, faster building rates in construction and lower haulage and handling costs.

2.2.2 Physical Properties of Lightweight Foamed Concrete

Chemical, mechanical and physical properties are some of most important parameter for the performance of foamed concrete to be measured. Foamed concrete is a versatile material with attractive properties and characteristics and as a result, it widely used in construction applications (Jones et.al, 2005).Properties of foamed concrete are such as fire resistance, thermal insulation, stability, density, air-void system, shrinkage, compressive strength, modulus of elasticity.

Density can be two states, which is fresh state or hardened state. Fresh density is required for mix design and casting control purposes. A theoretical equation for finding fresh density may not be applicable as there can be scatter in the results caused by a number of factors including continued expansion of the foam after its discharge, loss of foam during mixing (Regan et al., 1990). The density of lightweight concrete is dependent on the amount of foamed introduced in the concrete. High amount of foam will decrease the fresh density of the concrete. By specifying the density, moisture condition should be indicated as the comparison of the properties of foam concrete from different sources may have little meaning without a narrow definition of the degree of dryness (Valore, 1954). The density of foam concrete is 300 kg/m^3 up to 1800 kg/m^3 to suit different application. Usually, the lower densities of 400-600 kg/m^3 are ideal for thermal insulation applications. The density range 800-1000 kg/m^3 is utilized for making pre-cast blocks for non load bearing walling masonry in framed structures while the foam concrete range from 1200kg/m^3 to 1800 kg/m^3 is structural grade material utilized for in-situ casting of structural load bearing walls and roofs of low rise individual or group housing schemes or manufacture of reinforced structural cladding or partitioning panels or for making pre-cast blocks for loadbearing walling masonry for low-rise buildings.

McCormick, (1967) studied the effect of the types of fine aggregate, grading of aggregate, type of foam, and the relationship of cement – sand ratio in the wet density of aerated concrete and reported that wet densities within about 5% of the design density can be achieved by using solid volume calculations. The sand and cement concrete autoclave not based on preformed foam has a relatively higher density and higher cement content requirement. A greater proportion of aggregate, the greater the density.

The stability of foam concrete is at which the ratio of fresh density and fine density is nearly one, consider it is without any segregation and bleeding (Nambiar et al., 2006). The stability of foam concrete can also be assessed by comparing the calculated and actual quantities of foam required to achieve a plastic density within 50 kg/m3 of the design value and calculated and actual water cement (w/c) ratios.

The pore structure of the cementitious material predetermined by their porosity, permeability and pore size distribution as it is a very important feature, since it influences the properties such as strength and durability. The pore structure of the cellular concrete consists of gel pores, capillary pores and entrained and entrapped air voids. (Visagie et al., 2002). As foam concrete being a self-flowing concrete and self-compacting and coarse aggregate is missing in the mix the possibility of trapped air is negligible. A few factors such as volume, size, size distribution, shape and spacing between the air gaps are the parameter of air voids formed in the foamed concrete. The distribution of air-void is one of the most important properties influencing the micro-cellular concrete. Therefore, foamed concrete, with narrow air gaps distributions show a greater resistance of compressive stress.

Drying shrinkage are caused by withdrawal of water fromed concrete under the condition of humidity gradient between the interior of concrete and air. These are the two main factors contributing to cracking of concrete at early age. Foam concrete possesses relatively high drying shrinkage because of the absence of coarse aggregates in the mix compared to normal concrete (Jones et al., 2003). The higher values for foamed concrete also can be credited to its high cement and water content. The amount of drying shrinkage may also tends to increase with with decreasing density of the concrete by adding more foam in the concrete.

The cellular structure of foamed concrete contributes to good thermal insulating properties and low thermal conductivity values. The thermal conductivity of foam concrete of density is reported as 5% to 30% of those measured on normal concrete

(Jones and McCarthy, 2005). At high temperature, the heat transfer is influenced by radiation through porous materials, which is an inverse function of the number of air–solid interfaces traversed (Valore, 1954). Therefore, the foam concrete may produce better fire resistance properties due to its lower thermal conductivity and diffusivity. However, at high temperature, the foamed concrete undergoes an excessive shrinkage (Jones and McCarthy, 2005).

2.2.3 Mechanical Properties of Lightweight Foamed Concrete

Mechanical properties of lightweight foamed concrete is more related to the compressive strength, flexural or tinsile strenght, modulus of elasticity, direction of loading, age of samples, characteristic of the ingredients were used and method of curing.

Compressive strength reduces with decreasing foamed concrete density, reflecting the greater quantity of air bubbles present in the cementitious microstructure (Jones and McCarthy, 2005). There is a relationship between porosity of foamed concrete and the the compressive strength as the high porosity leads to lower compressive strength. The finess modulus of aggregates also affects the compressive strength of foamed concrete which finer aggregates lead to lower porosity of the foamed concrete which cause the higher compressive strength.

Flexural strength decreases as increasing water-cement ratios and decreasing concrete densities. It is estimated that values between 6% to 10% of the compressive strength obtained is the flexural strength of the foam concrete as been found by Jones and McCarthy, 2005.

Jones et al., (2005), reported that the dry densities between 500 and 1500 kg/m^3 would resulted the static modulus of elasticity of lightweight foamed concrete was lower than that of normal weight, with values typically varying from 1.0 kN/mm^2 to 8.0 kN/mm^2 respectively.

2.2.4 Application of Lightweight Foamed Concrete

Table 2.1: Application of Foamed Concrete

Density (kg/m³)	Applications
300 to 600 kg/m³	Lightweight and insulating cements for floors foundation, for heat insulation and slope for flat roofs, rigid floors foundation, tennis courts foundation, interspace concrete filling, raceways insulation; thermo insulating blocks, steel structures fireproofing, tunnels and pipelines compensating mass, dumps, foundation and coverings land reclamation and consolidation underground cavities infill and all types of infill where an elevated thermal insulation is required.
600 to 900 kg/m³	Stables and pig-sties foundations; industrial foundations, partition and tampooning slabs, ceiling slabs, concrete and Lightweights Concrete mixed panels.
900 to 1200 kg/m³	Blocks for outside walls, slabs for partitions, concrete and light weight concrete mixed panels for covering, foundations for elastic floors.
1200 to 1700 kg/m³	Prefabricated panels for civil and industrial buildings plugging; walls casting, gardens ornaments.

Source: Neville, 1985

Rudnai et al., (1963) and Narayanan et al., (2000) stated that lightweight foamed concrete also includes in structural elements, non-structural partitions and thermal insulating materials. Manufacturers developed lightweight foam concretes of different densities to suit the above requirements. The density of lightweight foamed concrete ranges from 300 kg/m3 to 1800 kg/m3 and these products were used in trench reinstatement, bridge abutment, void filling, roof insulation, road sub-base, wall construction, tunnelling etc.

According to Gao et. al, (1997) noted that self-weight represents a very large proportion of total load on the structure, and there are clearly considerable advantages in reducing the density of concrete in concrete construction. A decreased density of concrete for the same strength level permits a saving in dead load for structural design and foundation. Lightweight foamed concrete (LWC) has several and always increasing applications in all types of construction work. Some of the most common applications are shown in Table 2.1.

2.3 FINE AGGREGATES

Natural materials such as river sand and crushed fine stone are generally used in concrete as fine aggregates. However, with the growing in urban infrastructure development and the increasing demand on protecting the natural environment, especially in developed areas the availability of the natural resources is diminishing rapidly (Chi-Sun, 2009). Use of natural lightweight aggregates (such as diatomite, pumice, scoria, sawdust, oil palm shells, bottom ash etc.) instead of processed artificial aggregates (such as expanded shale, slate, perlite, sintered fly ash, vermiculite etc.) can significantly reduce the cost of such concretes. When cementitious fillers such as fly ash and incinerator bottom ash are used in foamed concrete, its compresive strength continue to increase in the long term when compared to sand mixed lightweight concrete which is unchanged after 60 days. Finding new and improved ways to build with such natural resources is becoming widespread and their use as construction materials can lead to low-cost construction (Hossain and Lachemi, 2007).

2.4 PALM OIL WASTES

Rasiah and Shahrin, n.d. stated that "Oil palm currently occupies the largest acreage of farmed land in both Malaysia and Indonesia having overtaken rubber and coconuts respectively. The first oil palm trees planted in Malaya came from Sumatra (Indonesia). Government promotion of oil palm started in these countries in the early and late 1960s respectively."

There are various forms of solid and liquid wastes from the mills. These include empty fruit bunches (EFB), palm press fibres (PPF), palm kernel cake (PKC), palm kernel shell (PKS), sludge cake (SC) and palm oil mill effluent (POME) (Prasertsan, 1996). PPF and PKS are used as burning materials in palm oil mill. They are burnt at 400°C for four hours which transform them into porous lumps which is known as palm oil clinker (POC).

2.4.1 Palm Oil Clinker

Palm oil clinker is a waste material obtained by burning of palm oil husk and shell as fuel in palm oil mill boilers. After palm oil is extracted from the palm oil fruit, both palm oil husk and palm oil shell are burned as fuel in the boiler of palm oil mill. The ash produced sometimes varies in tone of colour from greyish in colour, becoming dark with increasing proportions of unburnt carbon. In the other words, the physical characteristic of Palm oil clinker is very much influenced by the operating system in palm oil factory. Nowadays, Palm oil clinker produced in Malaysian palm oil mill is dumped as waste without any profitable return (Sumadi & Hussin, 1995). Since our country is continuously to increase production of palm oil, therefore more ashes will be produced and failure to find any solution. Thus, by utilization of this kind of waste material we can increase consequently leading to potential future environmental problem.

2.5 FACTORS INFLUENCING LIGHTWEIGHT FOAMED CONCRETE COMPRESSIVE STRENGTH

The compressive strength of lightweight foamed concrete is depend on many factors such as the sand to cement ratios (s/c), curing duration, water to cement ratios (w/c) and particle size distribution of sand. In this present section, the factor affecting the compressive strength of lightweight foamed concrete will be discussed.

2.5.1 Different Percentage of Artificial Aggregates

Researchs suggested that may increase or decrease compressive strength of concrete generally depending on the materials were replacing the aggregates and the percentage of the replacement. Al-Jabri, 2011 shows that copper slags can increase the concrete strength by replacing up to 60% of sand. Poon, 2009 suggested that 25% of sand being replaced by recycled aggregates showed adecrease of concrete compressive strength. This is due to the high initial free water content used in the mixes rendered bleeding and poorer interfacial bonding between the aggregates and the cement pastes. Siddique, 2003 shows that replacing fly ash can increase the compressive strength of concrete due to its pozzolanic properties of the fly ash. A greater proportion of aggregate, the greater the density. Compared with a product based on sand and cement, it is observed that substitution of sand with the aid of fly ash in the density reduction with increased strength (McCormick, 1967).

2.5.2 Different Density of Lightweight Foamed Concrete

Hamidah et al., (2005) studied on compressive strength of lightweight foamed concrete mix of different sand cement ratio and curing conditions was shown the compressive strength of lightweight foamed concrete increases as the density increases and sand-cement ratio decreases. That is means lower-density lightweight foamed concrete can achieve a strength equals to higher density foamed concrete by increasing the cement content. Otherwise cheaper mix of foamed concrete would only be possible at higher sand content. In a lower density foamed concrete, the amount of sand also limited to avoid segregation and collapse of the mix.

Generally, the density of a porous media is dependent on the amount of pores and pores size distribution in the media. It would have been expected therefore, that a higher density foamed concrete would record a higher compressive strength therefore, that a higher density foamed concrete would record a higher compressive strength due to its lower porosity. Narayanan (2000) studied the relationship between pore size and compressive strength. They concluded that the compressive strength is dependent on the amount or distribution of pores and pore sizes. The size and the amount of pores influence the compressive strength of a porous material, with smaller size air pores leading to higher compressive strength (Tang, 1986).

2.5.3 Curing Days

For lightweight foamed concrete (LWC), curing plays an important role for strength development. In this study, the compressive strength was tested at different curing condition of the LWC, which are water and air curing. The samples were cured in three different ages before test the specimen, namely 7 days, 28 days, and 90 days.

Once more it proves that the strength for air cured sample is higher than water cured sample (Shan, 1995). If the concrete properly cured, has fewer pores and crevices where water can enter, freeze and expand which will crack the concrete. Air entrainment helps make more durable concrete, but its use must also be accompanied by proper curing.

2.6 CONCLUSION

Lightweight concrete properties consist of a wide range of densities which depedant to the amount of foam in the concrete, possesses relatively high drying shrinkage because of the absence of coarse aggregates in the mix compared to normal concrete, and has lower compressive strength due to its high porosity relative to normal concrete. Using cementitious fillers such as fly ash and incinerator bottom ash or using finer aggregates can increase the compressive strength of the foamed concrete. The methods of preparing and testing the specimens are discussed in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the details explanations about methodology of compressive strength of foamed concrete with palm oil clinker as artificial aggregate. There were used sand, palm oil clinker, water, cement and foam agent to form the foamed concrete. All the samples of foamed concrete were cured in water tank for 7, 28 and 60 days. There are four types of different percentage of palm oil clinker were used namely 25%, 50%, 75%, and 100%. As a summary, there are 45 cube samples with density of 1600 kg/m^3 were prepared.

Compressive strength test were conducted to determine the physical properties of the lightweight concrete. Besides that, in this present chapter, the experimental plan and the implementation of the experiment that carried out thought the study were discussed. This chapter also consists of explanation on material use and brief on the testing method.

3.2 EXPERIMENTAL WORK

The experiment process flow for an evaluation of the compressive strength of lightweight concrete (LWC) due to different percentage of replacement as outlined in Figure 3.1 shows the flow chart of laboratory work.

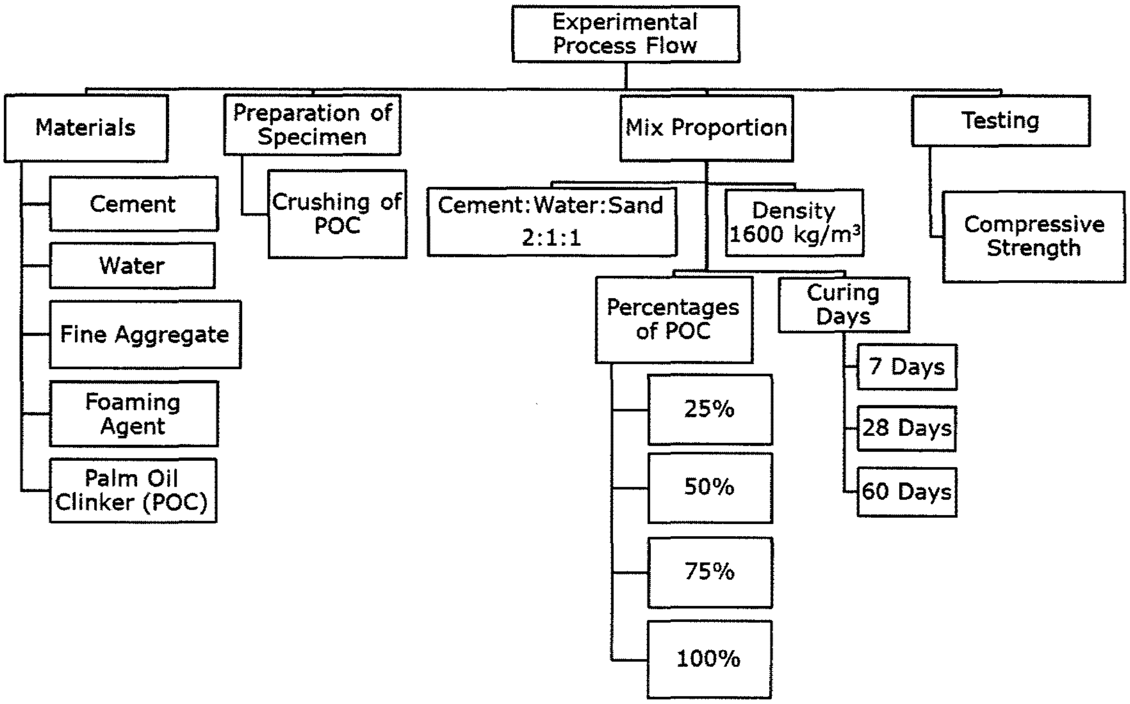

Figure 3.1: Experimental Work

3.3 MATERIALS SELECTION

Lightweight foamed concrete mixing by cement, fine aggregate, water, and foam agent. In this study, using palm oil clinker as sand replacement with a portion by total weight of sand. The palm oil clinker will be doing the soil properties in lab soil. Mix ratio that will been used in LWC is 2:1:1. This type of lightweight foamed concrete would use two parts of cement, one part of fine aggregate and one part of water.

3.3.1 Cement

The type of cement used in this research is Ordinary Portland cements type I (OPC) accordance to BS 12:1958. This can provide adequate levels of strength and durability are the most popular cements used by concrete producers. Portland cement is the most common type of cement used in all constructions including plain and reinforced cement concrete, brick and stone masonry, floors and plastering.

It is also used in the finishing of all types of buildings, bridges, culverts, roads, water retaining structures, etc. Furthermore, it surpasses BS: 8112: 1989 for 43 grade OPC on compressive strength levels. The ordinary Portland cement used is obtained from lab FKASA which weight 50 kg/bag.

3.3.2 Water

In this present study, tap water will be used which is the quality is accordance to MS: 28:1985 or BS: 3148:1959 that has been specified by the Public Work Department of Malaysia. Clean water is necessary material in mortar mix to forming concrete as it functions is to start hydration process of the cement.

The water that used in this study is obtained from lab FKASA and it is free of impurities. The ration of water to cement ratio is 0.5. This is to ensure that the lightweight foamed concrete is workable enough for mobility and concreting work process.

3.3.3 Sand / Fine aggregate

Sand can be describe into two major parts that is natural sand and crushed stone or crushing gravel sand. In this study, river sand that passed through a 5 mm (BS 410) test sieve was used. The diameter used are having diameter smaller than 5 mm. It must be clean and not contaminated by lumps of clay and also clean from salt ingredients. Figure 3.2 shows the sand was used in this study.

Figure 3.2: Fine aggregates

3.3.4 Palm Oil Clinker

Palm oil clinker (POC) is the by-product of palm oil milling process. The POC was taken from palm oil milling factory at FELDA Lepar Hilir, Pahang. The clinker was crushed with jaw crusher and then was crushed with aggregate crusher to produce finer size of aggregate.

3.4 PREPARATION OF SPECIMEN

Preparation of specimen can be divided into batching, mixing, and casting process. Minimum three samples were prepared for each parameter to be tested. The materials were used for LWC specimen's preparation is as follow:

i. Cube specimen preparation 150 mm x 150 mm x 150mm
ii. Raw materials
iii. Concrete Mixer
iv. Foam Generator
v. Compression test machine

A total of 45 cubes concrete will be test on compressive strength in lab of FKASA. Minimum three samples will be prepared for each percentage of POC and the samples must in accordance to BS 1881 Part 108:1983which each cube will have a dimension of 150 mm for its length, width and height. The number of samples prepared for compressive strength test is shown in Table 3.1. The methods used to mix the lightweight foamed concrete with palm oil clinker as artificial aggregate (LWC-POC) are as follows.

Firstly the cement, sand, water, and POC were weighed according to its specific proportions. Then, the cement, clinker and sand were mixed in a drum mixer until become a homogenous mix. After that, a portion of the water was poured and blended for two minutes in the drum. The remaining water was added as the drum continues to rotate. Then, the foaming agent was added until the required density which was 1600 kg/m^3 had been achieved. Lastly, the mix was poured into steel mould with dimension of 150 mm x 150 mm x 150 mm cubes for compressive strength test.

Table 3.1: Numbers of LWC specimens for Compression Test

Mix Design	**Mix Proportion**	**Percentage of POC (%)**	**Numbers of Sample**		
	Cement: Sand: Water		**7 days**	**28 days**	**60 days**
1600 kg/m^3	2:1:1	0	3	3	3
		25	3	3	3
		50	3	3	3
		75	3	3	3
		100	3	3	3

Figure 3.3: Steel Mould of LWC Cube

3.5 MIX PROPORTION

This section was explained the mix design of proportions of concrete by weight of materials which they contain or the required strength of the concrete specimens at a particular 28 days curing age. Mixed design is important in order to choose the best design mix of the ingredients to provide economical and the concrete desired properties in term of strength and durability. It consists of proportioning of the cement, fine and course aggregate and water.

3.5.1 Foamed Concrete Mix Design

In the study, lightweight foamed concrete (LWC) was produced by using the mix proportion of cement, sand and water with the ratio of 2:1:1. The density of LWC was design as 1600 kg/m^3.

Compressive strength will be due on LWC by replaced with different percentage of POC as fine aggregate. The mix proportions were cured by air curing. The mix design contains cement, water, fined aggregate, foam agent without replace with POC were consider as a control mix.

For both mix proportion design, the ratio of sand-cement (s/c) and ratio for water-cement ratio (w/c) were constant at 0.50. The lightweight foamed concrete are mix with different percentages of POC namely 0% as a control mix, additionally of 25%, 50%, 75%, and 100% palm oil clinker from the total weight of sand as shown earlier in Table 3.1.

3.5.2 Determine Weight of Raw Materials

In this study, the mix proportion of cement, sand, and water was 2:1:1 and the density of 1600 kg/m^3. Table 3.2 shows the weight of raw materials preparation for 1m^3.

Table 3.2: Weight of Raw Materials for LWC in 1m^3

Mix Density	Cement: Sand: Water	Cement (kg)	Sand (kg)	Water (*l*)	Foam Agent (*l*)
1600kg/m^3	2 : 1 :1	800	400	400	192

3.6 CURING METHOD

Curing is a process where concrete were 'treated' before it can be tested. The process is concrete specimen were placed into water tank and leave it for the certain period. The purpose of curing is to make sure the concrete have proper process of hardened and the cement in concrete specimen fully reacts with water and the bonding is good.

3.6.1 Air Curing

This is probably the easiest and most popular method of curing. It is a slow, but acceptable system which enables a turnaround of moulds every 24 hours on average, depending on the ambient temperature. Curing techniques using air drying are utilized in the situation where curing by water curing is not practical (Al-Gahtani, 2010). With the increasing lack of water, there is pressure on the construction industries to decrease its consumption of water.

3.7 COMPRESSIVE STRENGTH TEST

The compression test was conducted by using compressive test machine at concrete laboratory of Faculty Civil Engineering and Earth Resources of the Universiti Malaysia Pahang as specified in the test method BS 1881: Part 116, 1983. An increasing compressive load was applied to the specimens until failure occurred to obtain the maximum compressive load. The specimens are prepared according to the ASTM C 39, 2004. Those mixes poured into mould and after 24 hour, the mould been erected and the cubes is cured in water tank for 7, 28, and 60 days of curing age. The specimens were taken when it's matured till the 7, 28, and 60 days of curing as shows in Figure 3.4.

Figure 3.4: Cube prepared for compressive strength test

Any accumulated debris was removed from the front of the specimen in each of the specimens. The test initiated with the specimen dimension was taken before the testing, then the specimen will be placed properly at the centre of compressive machine and the compressive force was applied symmetrically and gradually at a nominal rate of

1 kN/sec. Figure 3.5 shows the compressive strength test apparatus used in this study. The force is imposed until the specimen is satisfactory failure. The compressive load value is noted.

Figure 3.5: Compressive strength test machine

3.8 CONCLUSION

This chapter involves planning for methods in constructing laboratory work. A total of 45 cubes with different percentage of POC replacing sand in LWC will be compared in terms of compressive strength for 7, 28 and 60 curing days. Based on the methodology discussed in this chapter, compressive test will be conducted to determine the objective of this study. The results of this laboratory work will be presented on the next chapter.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the results on compressive strength of the mix M0, M25, M50, M75 and M100 which is 0%, 25%, 50%, 75% and 100% of sand's weight is replaced by palm oil clinker. Results and analysis of this study are based on the data collected from the laboratory experiments that has been done. In this study, the density of lightweight foamed concrete (LWC) used are 1600 kg/m^3 with the ratio of 2:1:1 composed of cement: sand: water. In addition, 25%, 50%, 75% and 100% of sand weight in the LWC will be replaced with palm oil clinker.

In this present section, the discussions and data analysis of LWC due to compressive strength of LWC will be discussed. The approach of using different percentage of palm oil clinker as sand replacement also will be presented.

The compressive strength test was conducted in the laboratory by using a compressive testing device. There are 45 number cubes prepared and tested to obtain the compressive strength due to 7 days, 28 days, and 60 days. Respectively there are 5 types of LWC samples would be considered, namely control sample (M0) and LWC with different percentage of palm oil clinker as sand replacement which composite of 25%, 50%, 75% and 100% by total weight of sand. The compressive strength is influenced by the curing conditions, specimen preparation, age at testing, mode of testing, and mode of failure of the specimen (Neville, 1987).

4.2 COMPRESSIVE STRENGTH OF FOAMED CONCRETE WITH POC DUE TO DIFFERENT CURING AGES

In this present section, the result on compressive strength test will be present details of the compressive strength of M0, M25, M50, M75, and M100. The compressive strength test is carried out to determine the strength of the LWC at ages 7, 28 and 60 days. The main purpose of this test is to determine the strength of the sample by using POC. The mix proportion of the samples is 2:1:1 which comprises of cement to sand to water. The sand was replaced with palm oil clinker (POC) from the total weight of sand. At the time of testing, the cured specimens were surface dried. The compressive strength was calculated by compressing 150 mm x 150 mm x 150 mm cubes. It is noted that the compressive strength increases with age. Narayanan et al., (2000) stated that method of curing influence the physical and mechanical properties of foamed concrete.

Figure 4.1 shows the compressive strength results for 7, 28 and 60 days of curing for plain foamed concrete as control mix (M0) which is 0% of palm oil clinker replacement. It shows that the strength of the LWC is increased with increasing of curing days. The LWC attained its highest strength at the sixtieth day of curing, which is 20.3 MPa.

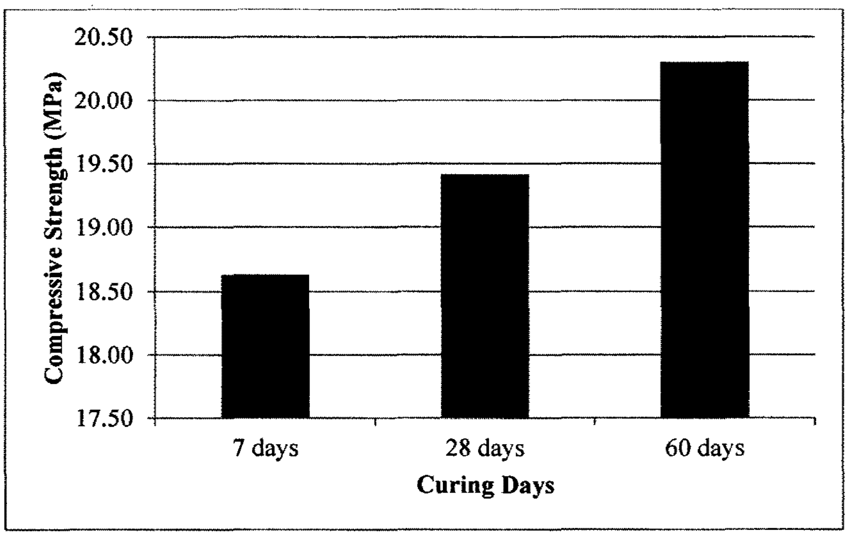

Figure 4.1: Compressive Strength of LWC with 0% of POC

Result on compressive strength at 7, 28 and 60 days of curing ages of 25% POC as sand replacement with density 1600 kg/m^3 was subjected in Figure 4.2. Figure 4.2 illustrated that the compressive strength was increased with increasing curing days. The range of compressive strength is between 21.37 MPa to 23.51 MPa. The compressive strength achieved the optimum strength at 23.51 MPa at 60 days curing ages. The percentage of increasing is about 10%. Table 4.1 shows the difference in terms of compressive strength between M0 and M25. By replacing 25% of sand with POC shows an increase of compression strength by 14.54% at 7 day strength and the difference increases as the curing days increases.

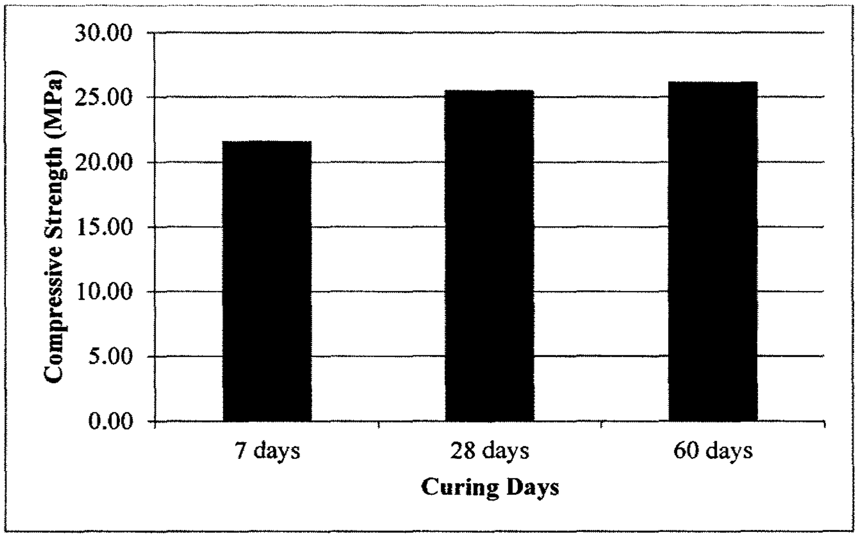

Figure 4.2: Compressive Strength of LWC with 25% of POC

Table 4.1: Difference of Compressive Strength between M0 and M25

Curing Days	Control	25%	Difference (%)
7 days	18.63	21.37	14.70
28 days	19.42	22.24	14.54
60 days	20.30	23.51	15.79

The results on compression strength of foamed concrete with 50% of POC (M50) subjected to different curing days are shown in Figure 4.3. It is clearly shown that the compressive strength value increased commonly due to the days. It displayed that the compressive strength attained at 21.61 MPa for 7 days of curing. The compressive strength value increased drastically for 28 days and achieved the optimum strength at 26.16 MPa for 60 days of curing. The percentage of increasing from 7 days to 28 days is 18.14% while 2.47% from 28 days to 60 days. Table 4.2 shows the difference in terms of compressive strength between M0 and M50. By replacing 50% of sand with POC shows an increase of compression strength at least by 15.99% at 7 day strength and the difference increases as the curing days increases. Ay 60^{th} day of curing, the difference decreased but the compressive strength is still higher than M0.

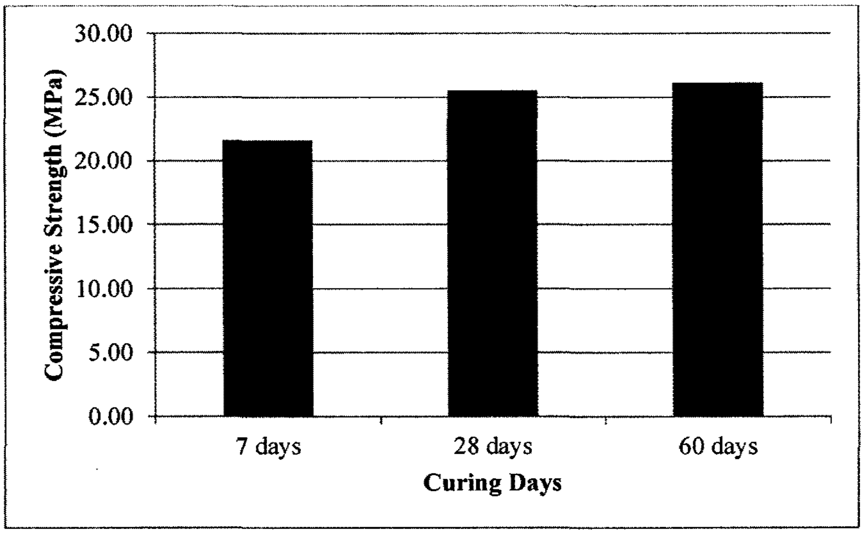

Figure 4.3: Compressive Strength of LWC with 50% of POC

Table 4.2: Difference of Compressive Strength between M0 and M50

Curing Days	Control	50%	Difference (%)
7 days	18.63	21.61	15.99
28 days	19.42	25.53	31.48
60 days	20.30	26.16	28.83

The result on compressive strength of LWC for 7, 28 and 60 curing days with density 1600 kg/m^3 when subjected to 75% of POC as sand replacement were presented in Figure 4.4. Figure 4.4 demonstrated that the compressive strength was increased frequently in 7 days to 60 days. Furthermore, Figure 4.3 shows that the compressive strength was attained at 22.90 MPa at 7 days of curing and increased at optimum strength of 28.82 MPa at 60 days. The percentage of increasing is about 25.85%. Table 4.3 shows the difference in terms of compressive strength between M0 and M75. By replacing 75% of sand with POC shows an increase of compression strength at least by 22.90% at 7 day strength and the difference increases as the curing days increases. Ay 60th day of curing, the difference decreased but the compressive strength is still higher than M0.

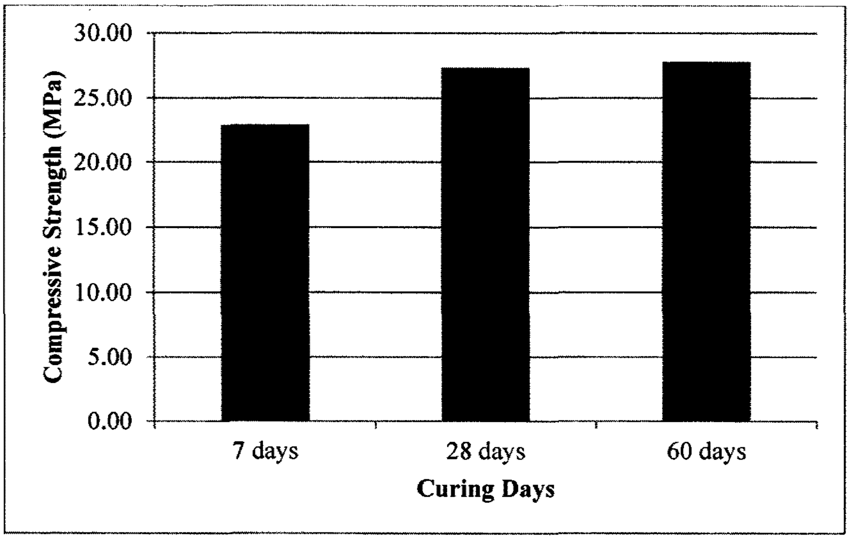

Figure 4.4: Compressive Strength of LWC with 75% of POC

Table 4.3: Difference of Compressive Strength between M0 and M75

Curing Days	Control	75%	Difference (%)
7 days	18.63	22.90	22.90
28 days	19.42	27.39	41.05
60 days	20.30	27.82	37.02

The relationship between the compressive strength and POC is shown in Figure 4.5. As compared to the compressive strength of different curing days, the compressive strength of samples type M100 for 7 days increased by 1.8% on 28 days. Meanwhile the percentage of increasing from 28 days to 60 days is 10.59%. Initially the strength of the sample increases rapidly with respect to the curing time from the LWC is casted and then the rate of change in terms of compressive strength is decreased after the seventh day of curing. Table 4.4 shows the difference in terms of compressive strength between M0 and M100. By replacing 100% of sand with POC shows an increase of compression strength by 15.96% at 7 day strength and the difference increases as the curing days increases.

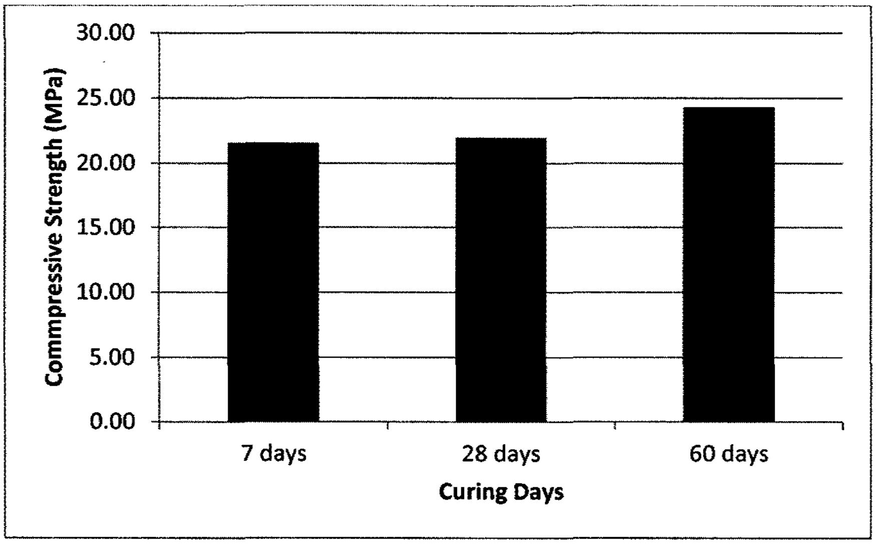

Figure 4.5: Compressive Strength of LWC with 100% of POC

Table 4.4: Difference of Compressive Strength between M0 and M100

Curing Days	Control	100%	Difference (%)
7 days	18.63	21.61	15.96
28 days	19.42	22.00	13.29
60 days	20.30	24.33	19.85

4.2.1 Discussion on Compressive Strength of Foamed Concrete with POC due to Different Curing Ages

As a comparison on the data obtain in determine of effect on different percentage of lightweight foamed concrete with palm oil clinker (LWC-POC), an analysis are done based on the data collected from the test and the comparison the compressive strength between the LWC-POC as sand replacement were also investigated in Figure 4.6. It clearly shows the compressive strength of LWC due to different percentage of POC as sand replacement in each mixture as shown in Figure 4.6. It is revealed that the increasing of compressive strength due to percentage POC as sand replacement.

For 7 days of curing LWC-POC using 75% as sand replacement obtained the highest followed by 25%, 50%, and 75% of POC and last 0% of POC. For 60 curing days, compressive strength of LWC-POC using 75% as sand replacement obtained the highest strength followed by 25%, 50%, and 75% of POC and last 0% of POC. The 75% of POC as sand replacement obtained the highest compressive strength which is the optimum value of sand replacement in LWC. The 75% of POC as a replacement of sand is most suitable to intensify the strength of cement and increase the compressive strength.

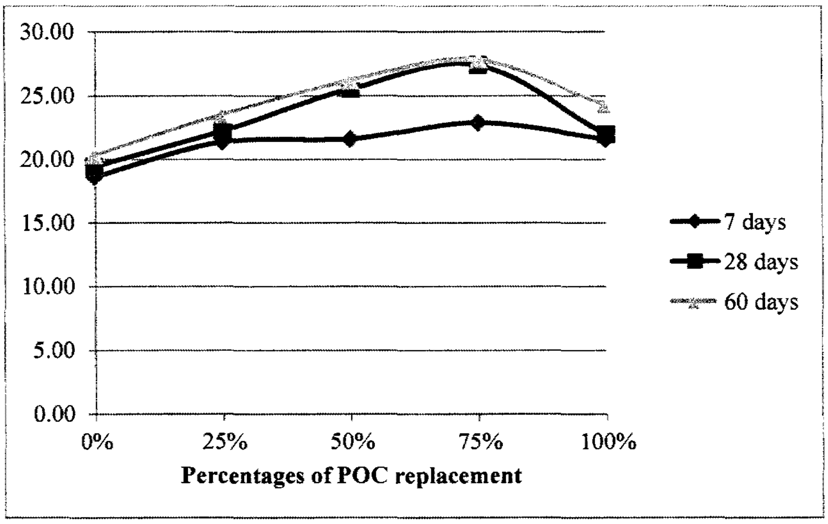

Figure 4.6: Compressive Strength with Different Percentage of Palm Oil Clinker Crushed (POC)

The increases of compressive strength were influenced by water-cement-to ratio in the samples. Besides that the high compressive strength due to POC can be related to the increase of the quantity of water entrainment in samples during the curing period. According to Chindaprasirt (2008), at the age of 7 days, the concrete strength developed through the production of CSH (Calcium Silicates Hydrates) was lower than the strength of POC aggregates. Thus, the paste acts as the weakest part of the concrete and becomes the location of stress concentration and crack formation. However, at 28 days, the increase in production of CSH increased the paste strength causing the shift of some stress concentration and cracks to the weaker component of the concrete which is the POC aggregates.

The result of compressive strength might be affected on the different size of sand and mix proportion used in producing specimen. Kunhanandan and Ramamurthy (2006) found that the fineness of sand produces higher compressive strength of LWC. Besides that, the different chemical composition of cement and foaming agent is also a factor for the different compressive strength. According to Aldridge (2005), the mixture ratio between the cement, water and sand, curing regime, type and particle size distribution of sand and type of foaming agent used also will affecting the strength of LWC.

Besides that, Van (2002) mentioned that the longer curing period of foamed concrete does not produce a weaker material or samples. The samples become stronger when period of curing increase while the compressive strength of foamed concrete also increase. Longer curing time may improve the polymerization process resulting in higher compressive strength.

4.3 COMPRESSIVE STRENGTH OF FOAMED CONCRETE DUE TO DIFFERENT PERCENTAGE OF POC

The result on lightweight foamed concrete with palm oil clinker (LWC-POC) due to compressive strength at 7 days curing age is shown in Figure 4.7. Surprisingly, as seen in the figure, it is clearly shown that the strength for 75% of palm oil clinker crushed (POC) used as sand replacement is better than other samples with is using different percentage of POC. Even at 25% of replacement can increase the LWC strength.

Figure 4.7 displayed the compressive strength of 75% of POC as sand replacement is higher than 25%, 50%, and 100% of POC used as sand replacement. As observed, the percentage of increasing strength is 22.92% of with 75% of sand replaced with POC compared to control sample (M0). On the other hand, M25 was 14.71% higher in compressive strength compared to M0. The result shows that when 50% and 100% of sand was replaced with POC, the compressive strength increased by 16.29% when compared to M0 of LWC. Based on results, the compressive strength was increased by replacing a percentage of sand with POC with 75% of sand replacement with POC as the optimum level of replacement.

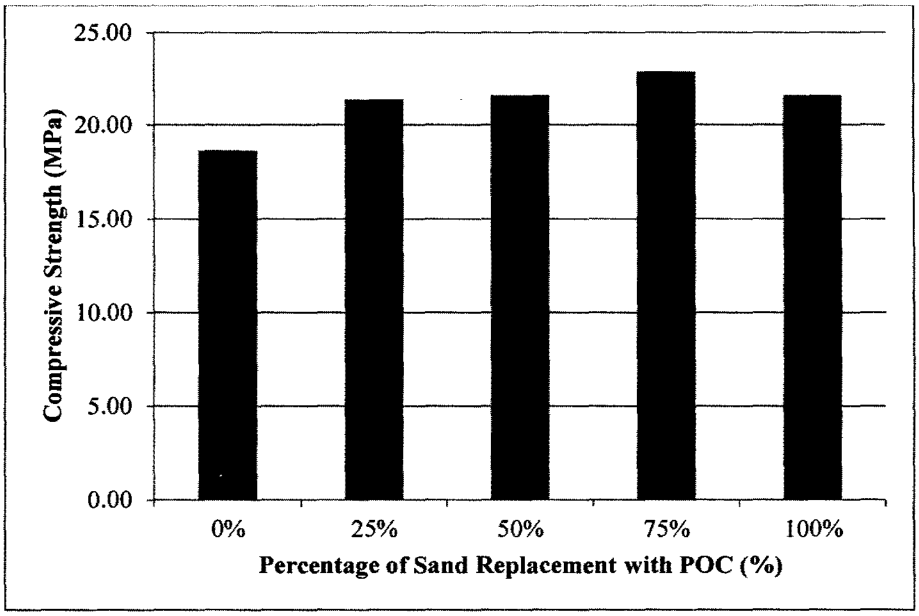

Figure 4.7: Compressive Strength of LWC-POC at 7 Days of Curing Ages

The results on compressive strength for 28 day of curing age with density 1600 kg/m3 where subjected to control mix (M0, M25, M50, M75, M100) which is 0%, 25%, 50%, 75%, and 100% of sand replacement with POC were shown in Figure 4.8 below. Figure 4.8 compares the compressive strength of these samples to the curing aged which is higher and lower value. The amount of increasing from 0% to 25% of POC is 2.82 MPa while 6.11 MPa for 50% compared to the control mix. A difference of 7.97 MPa in terms of compressive strength between M75 and the control mix. The compressive strength is increased due to replacement of sand with POC was clearly shown in Figure 4.8.

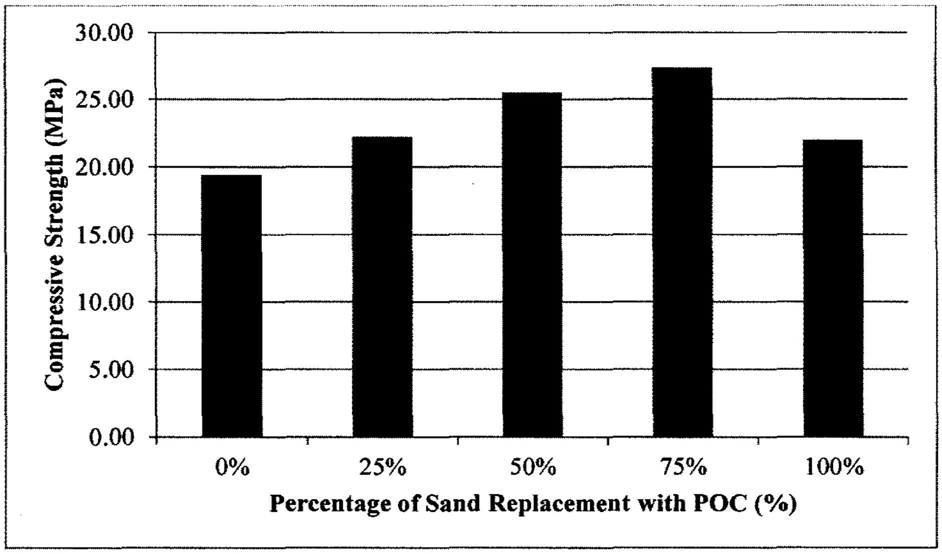

Figure 4.8: Compressive Strength of LWC-POC at 28 Days of Curing Ages

From the Figure 4.9, it is clearly shown that the LWC with 75% POC as sand replacement samples achieved the highest strength compared to the others. The second highest strength is M50 that is LWC with 50% of sand is replaced with POC. The third is the samples of LWC with 100% POC and the forth compressive strength is LWC added with 25% POC sample. The control mix has the lowest strength. The compressive strength of LWC control sample is 20.30 MPa while the compressive strength of LWC with 25% POCC as sand replacement is 23.51 MPa, which is 15.81% higher than the compressive strength of the control sample. Meanwhile, LWC with 50% POC as sand replacement is 26.16 MPa and LWC with 75% POC as sand replacement is 27.82 MPa. Lastly, LWC with 100% of sand replaced with POC has compressive strength at 24.33 MPa.

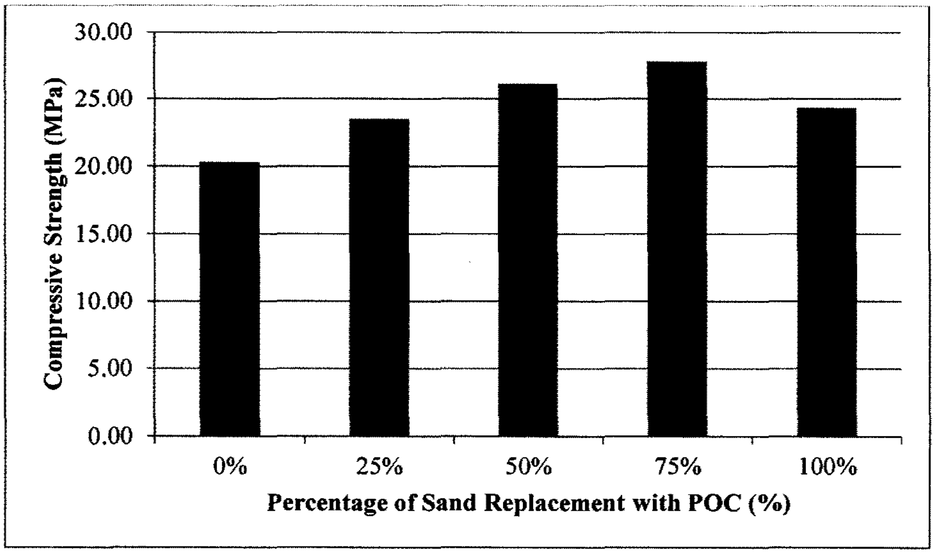

Figure 4.9: Compressive Strength of LWC-POC at 60 Days of Curing Ages

4.3.1 Discussion on Compressive Strength of Foamed Concrete with Different Percentage of POC

This section presents the results on compressive strength of the foamed concrete tested at the age of 7, 28 and 60 days. Discussing on the compressive strength of specimens studied, Figure 4.10 clearly shows that application of different percentage of POC influence the compressive strength of the foamed concrete.

According to that figure, the compresslve strength for LWC has increased frequently from curing days of 7 to 60 days. This present section was discussed the effect of using different curing days such as 7, 28, 60 days. Compressive strength of LWC with 75% of POC as sand replacement has the highest strength compared to other LWC samples on 7 curing days which is followed by the 50%, 100%, 25% and lastly 0%. This is because during 7 days curing duration, the LWC only reached its early strength, so is still in the mature rate. The compressive strength increased when the curing days increased. The two properties are evaluated in terms of consistency and stability of LWC, which are affected by the water content in the base mix, amount of foam added along with the other solid ingredient in the mix (Ramamurthy, 2009).

LWC with higher compressive strength value was obtained due to increasing curing ages. From this comparison, it is known that curing process was the important process where the LWC develops its strength. The development of good compressive strength in curing is contributed to sufficient moisture and suitable vapor pressure, which were maintained to continue the hydration of cement (Ling and Teo, 2011). On the other hand, the presence of foam in cement would delay the hydration and thus it is expected that LWC could achieve maximum strength at later ages of curing (Puttappa, 2008). The production of secondary calcium silicate hydrate from hydration process was hindered in absence of water but the dilution of foaming agent provides excess water content for sufficient internal curing.

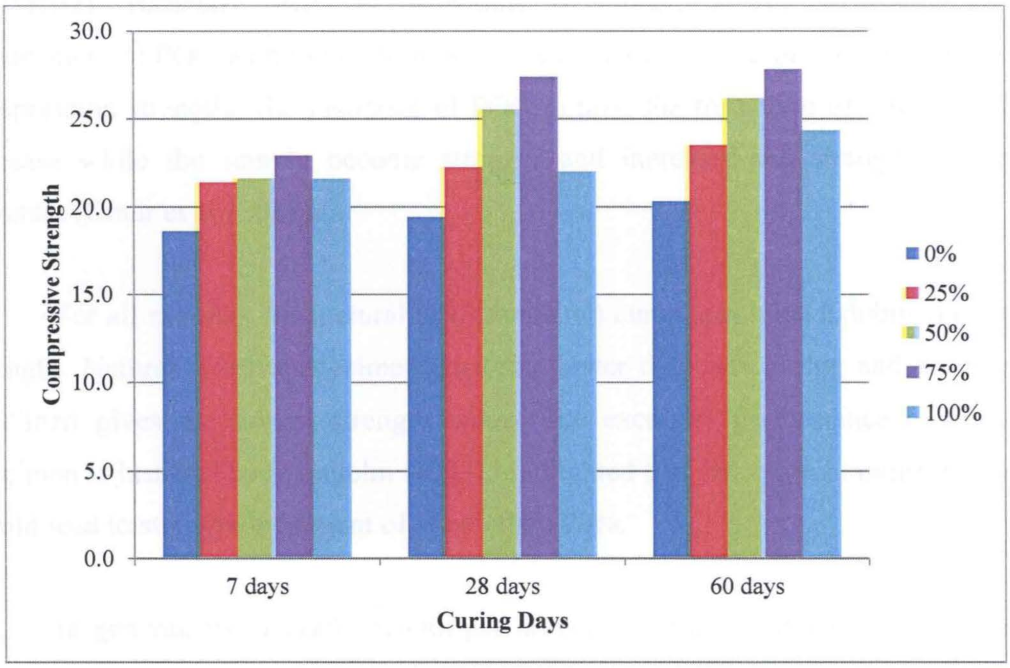

Figure 4.10: Summary Result on Compressive Strength of LWC-POC at Different Curing Ages

Improper curing can easily reduce strength of even the LWC. Curing simply means keeping the water in the LWC where it can do its job of chemically combining with the cement to change the cement into tough "glue" that will help develop strong, durable LWC. Good curing means keeping the LWC damp the LWC is strong enough to do its job (Anon, 2009). The compressive strength was tested at different curing condition of the concrete, which are water and air curing, obviously shows that the strength of air cured specimen is much better than the water cured (Shan, 1995). Kearsley (2000) stated that the compressive strength decreases exponentially with a reduction in density of L WC. The compression strength will be influenced by the specimen size and shape, the method of pore formation, direction of loading, age, water content, characteristics of ingredients used and the method of curing.

Each of the test data points plotted in various graphs corresponds to the mean value of the compressive strengths of different percentage of POC used. Firstly, Portland cement is mixed with water, the hydraulic process of cement starts which results in the formation of calcium silicate hydrate (C-S-H) and calcium hydroxide (Ca(OH)2). Basically, POC is containing of silicate hydroxide (Si02). By the replacement of POC with sand into foamed concrete mix, the results in the increment of compression strength. The increases of POC in mix, the formation of Si02 from POC increase while the sample become stronger and increased the strength of foamed concrete (Omar et al., 2001).

For all samples, air (natural environmental) cured specimen exhibits the highest strength. Natural weather specimen performs better than wet curing and water cured specimen gives the lowest strength value. The excellent performance of air cured specimen is justified by Svanholm (1983) highlighted that reduction in moisture content would lead to strength increment of about 40 to 70%.

In general, the overall strength performance of the specimens is influenced by the moisture content in it whereby increment in moisture content of the sample to reduction in the strength exhibited. Similar fact has been highlighted by Narayanan et al., (2000) mentioned that increase in moisture content of aerated concrete will cause decrease in its compressive strength.

4.4 CONCLUSION

Based on the results shown, it is known that by replacing sand with POC can increase the compressive strength of LWC. POC have similarities with other pozzolanic materials which increase the strength of concretes. The optimal replacement of sand is 75% which shows an increment of compressive strength of 37.02% at 60 curing days' strength. The present chapter had explained about the analysis of results obtained from the laboratory work. The data analysis consists of two types of analysis which are compressive strength of foamed concrete with POC due to different curing ages and compressive strength of foamed concrete with different percentage of POC

The overall conclusion including problems that occurred during the laboratory works and the recommendations can be referred on the final chapter.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The main objective of this present study is to determine the compressive strength of lightweight foamed concrete (LWC) using different percentage of palm oil clinker (POC) as sand replacement subjected to different various POC and curing day. The variables of mix proportion which using different percentage of POC as sand replacement with weight of sand were used to obtain the compressive strength. LWC itself were used for control, sample to compare LWC with different percentage POC as sand replacement namely 25%, 50%, 75% and 100%. Different ages of curing in LWC which are 7, 28, and 60 days. An analysis of the data was conducted to obtain the compressive strength towards achieving the objective of the study.

5.2 CONCLUSIONS

The replacement of crushed palm oil clinker with sand in Portland cement shows an increase in compressive strength of 15.81%, 28.87%, 37.04% and 19.85% respectively for sample type M25, M50, M75 and M100 compared to that of control sample. This is because POC may have some pozzolanic properties.

It is also noted that, the increasing of curing days significantly affected the strength subjected to compressive strength. Curing has a strong influence on the properties of hardened concrete such as strength, durability, watertightness, abrasion resistance, volume stability, and resistance to freezing and thawing and deicer salts (Shi, 2012). Therefore, the LWC could achieve maximum strength at later ages of curing.

It is appeared that the optimum mix design of LWC-POC was produce by using 75% of POC as sand replacement. According to Lo (2007), increase in pore numbers within the cement paste and in the aggregate/cement paste interfacial zone leads to a corresponding decrease in concrete strength. This indicates that LWC-POC need a part of sand in the mix to ensure the LWC will have low porosity that leads to a higher compressive strength.

5.2 RECOMMENDATION

Overall, the application palm oil clinker crushed (POC) as sand replacement is suitable in lightweight foamed concrete (LWC) mix. This material has a potential to use in the construction industry in future. The research need to be done more to improve the characteristic of the material. Some recommendations are done to improve the material:

i. A series of investigation on the effect of the LWC with POC using several of water to cement ratios.

ii. A series of investigation on durability aspect of the LWC due to the resistance of the LWC to the chemical attack should be conducted.

iii. A series of investigation on mechanical tests for the POC foam concrete such as flexural test, shrinking and expanding should be conducted.

iv. A series of investigation on various curing condition should be considered.

v. A series of investigation on combining other mineral such as fly ash, silica fume, rice husk ash or palm oil fuel ash as sand replacement should be considered.

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APPENDIX A

COMPRESSIVE STRENGTH OF LWC CUBES

Days	7 days			Average
0%	18.23	19.38	18.29	18.63
25%	20.49	21.04	22.59	21.37
50%	20.91	20.79	23.14	21.61
75%	24.15	21.18	23.37	22.90
100%	21.33	24.27	19.22	21.61

Figure A.1: 7 day Compressive Strength of LWC cubes

Days	28 days			Average
0%	18.59	19.54	20.12	19.42
25%	22.9	24.18	19.64	22.24
50%	25.08	25.83	25.68	25.53
75%	27.36	26.76	28.04	27.39
100%	20.77	24.55	20.67	22.00

Figure A.2: 28 day Compressive Strength of LWC cubes

Days	60 days			Average
0%	19.8	21.09	20.02	20.30
25%	25.46	25	20.07	23.51
50%	26.04	26.34	26.09	26.16
75%	28.36	28.35	26.75	27.82
100%	24.37	25.66	22.97	24.33

Figure A.3: 60 day Compressive Strength of LWC cubes