COMPRESSIVE STRENGTH OF ULTRA-HIGH PERFORMANCE CONCRETE INCORPORATING PALM OIL CLINKER AS AGGREGATE REPLACEMENT AT DIFFERENT ELEVATED TEMPERATURES

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ABSTRAK

Konkrit berprestasi tinggi (UHPC) adalah bahan pembinaan dengan sifat-sifat mekanikal yang cemerlang dan ketahanan yang baik berbanding dengan konkrit biasa. Di sebalik ciri-ciri yang cemerlang, UHPC juga mempunyai beberapa batasan dari segi ketersediaan bahan konstituen mentah. UHPC memerlukan sejumlah besar batu kelikir untuk menghasilkan UHPC. Oleh itu, penggunaan bahan buangan iaitu klinker kelapa sawit (POC) sebagai elemen gantian untuk batu kelikir di UHPC adalah satu penyelesaian yang menjanjikan bagi menyelesaikan masalah ini. Idea ini juga diilhamkan daripada isu-isu alam sekitar penting yang terhasil daripada pelupusan sisa kelapa sawit. Ia bukan sahaja mengurangkan kemusnahan, tetapi ia juga memberi petunjuk kepada pembangunan mampan dengan memastikan pemuliharaan sumber semula jadi. Walaupun UHPC mempunyai sifat-sifat mengkagumkan dan kekuatan, UHPC menghadapi cabaran yang besar dengan api dan suhu yang tinggi. Dalam kajian ini, kemungkinan untuk menggunakan POC sebagai penggantian agregat disiasat. Empat (4) peratusan tahap POC sebagai penggantian batu kelikir yang berbeza telah disediakan. Terdapat 0%, 5%, 10% dan 15% dari POC dari berat jumlah batu yang digunakan. Dalam kajian ini, spesimen telah dipanaskan di dalam relau pada 200° C, 400° C, 600° C dan 800° C selama satu (1) jam. Kemudian, sifat-sifat kekuatan spesimen dari segi kekuatan mampatan pada 7, 28 dan 60 hari telah disiasat. Kegagalan mod spesimen dengan dan tanpa POC selepas tertakluk kepada suhu yang tinggi telah diperhatikan dan dikaji.

ABSTRACT

Ultra-high performance concrete (UHPC) is a construction material with excellent mechanical properties and good durability as compared to conventional concrete. Despite its outstanding properties, UHPC also has some limitations in terms availability of raw constituent materials. UHPC require large amount of coarse aggregate in the production of UHPC. Therefore, the incorporation of waste material namely palm oil clinker (POC) as aggregate replacement in UHPC is a promising solution to these arising problems. This idea also was inspired from the crucial environmental issues that resulting from the disposal of palm oil waste. It not only minimize the degradation, but it also guides to sustainable development by ensuring the conservation of natural sources. Eventhough UHPC has impressive properties and strength, UHPC are having big challenge with fire and high temperature. In this study, the possibility of using POC as aggregate replacement was investigated. Four (4) different percentages of levels POC as aggregate replacement were prepared. There are 0 %, 5 %, 10 % and 15 % of POC from total weight of aggregate used. In this study, the specimens were heated in the furnace at 200°C, 400°C, 600°C and 800°C for one (1) hour. Then, the strength properties of specimens in terms of compressive strength at 7, 28 and 60 days were investigated. The mode failure of specimens with and without POC after subjected to high temperatures were observed and studied.

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LIST OF SYMBOLS

°C	Degree celcius
%	Percentage
Kg/m^3	Kilogram per cubic meter
mm	Millimeter
MPa	Megapascal
N	Newton
P	Applied load
μm	Micrometer

LIST OF ABBREVIATIONS

BS	British Standard
CA	Chemical admixture
HPC	High performance concrete
HRWR	High range water-reduce
NC	Normal concrete
OPC	Ordinary portland cement
PCC	Plain cement concrete
SF	Silica fume
SP	Superplasticizers
UHPC	Ultra-high performance concrete
UHPFRC	Ultra-high performance fibre reinforced concrete
w/c	Water-cement ratio

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

A new class known as ultra-high performance cement (UHPC) has been developed in conjunction with the advances in concrete technology and has become a new focus for the concrete industry (Rahman et al., 2005 and Serelis et al., 2015). Ultra high performance concretes (UHPCs) are cementitious composite materials with high level of performance characterized by high compressive strength, high tensile strength and superior durability. These are reached by a low water-to-binder ratio, optimized aggregate size distribution, thermal activation, and fiber reinforcement. The compressive strength of UHPC can be more than 100 MPa according to Vogel et al. (2008) and Karmout (2009). Various approaches to ultra-high performance improvement have been developed. UHPC has been generally formulated using coarse, fine and ultrafine aggregates, low water ratios, silica fume and high cement ratios (Shihada and Arafa, 2010).

Despite of its outstanding properties, the availability of raw materials also imposes certain limitations for UHPC. Large quantities of UHPC must be produced by sand, aggregates and cement. This has led to natural resources being depleted, which today is one of the major challenges of concrete industry. Aggregates can be viewed as the most dominant material in UHPC production with regard to the material component in UHPC. Gravel is usually used in UHPC mixtures and it provides an idea to seek other natural raw material sources for substitutions due to its high cost of gravel.

On the other viewpoint, the disposal of the waste materials from industry such as rice husk, slag, fly ash and palm oil is one of the most crucial environmental issues all around the world. Palm oil waste is one of the significant waste that should be more concerned. The high amount of waste generated is mostly composed of palm oil clinker (POC) and palm oil shell. POC is a by-product of the incineration of palm oil shells. It is a light, solid, and fibrous material that can be used in crushed concrete as a potential light-weight aggregate. A previous study by Canadasan and Abdul Razak (2015) shows that using POC reduces cost and energy consumption and reduces carbon emissions. A feasibility study carried out on POC aggregates confirm that POC is able to reduce mortar densities by 7 % between 0.035 and 0.05 MPa/kg m^3 in terms of its structural efficiency. Abdullahi and Al Mattarneh (2014), has investigated POC concrete mixing proportions to precisely assess POC aggregate properties such as distribution of particle size, specific gravity and water absorption.

There have been a lot of efforts in recent decades to improve UHPC's mechanical features. For example, some nano-materials have recently been examined as a new UHPC additive (Y.Su et al., 2016). However, fire or high temperature is still a great threat to all kinds of concretes including UHPCs. Tai et al. (2011) reported an increase in compressive strength of UHPC specimens heated up to 300 °C; however, a decreasing trend in compressive strength was observed beyond 300 °C. The declining trend in mechanical properties of UHPC at elevated temperature was mainly due to the weakening of internal microstructure (Li and Liu, 2016). An improved behavior at elevated temperature was observed with the addition of steel fibers in UHPC specimens (Tai et al., 2011; Li and Liu, 2016; Zheng et al., 2012). The compact structure and low porosity of UHPCs are usually more severe than those of NSCs. Consequently, the development of UHPCs with better fire resistance is very important.

Mun (2007) and T.Y.Lo et al. (2008) reported that concrete incorporating POC enhances thermal and fire resistance. Therefore, the exploration on the production of UHPC incorporating POC was investigated in the present study. In order to investigate the strength properties of specimen at different elevated temperatures, a plain UHPC and three (3) series of POC-UHPC mixtures were designed.

1.2 Problem Statement

Ultra-high performance concrete (UHPC) is a construction material with excellent mechanical properties and good durability. The conventional UHPC basically includes steel fibers that enhance both UHPC tensile strength and ductility (Richard and Cheyrezy, 1995; Eide and Hisda, 2012; Gu et al., 2015). The common use of steel fiber probably would be due to the many advantageous properties of this type of fiber: high elasticity modulus, high strength, high ductility and excellent durability in alkaline concrete environments. The addition of steel fibres contributed to the higher cost of construction material. Therefore, an alternative construction materials with similar properties should be explored to replace the steel fibres in UHPC.

Malaysia is one of Asia's primary palm oil producers. It is the world's second largest palm oil producing country, producing over half of the world's annual palm oil. Malaysia generates approximately 3.13 million tons of palm shells as waste, which is expected to grow due to the ongoing global demand for palm oil (H.Basri, 1999). Palm oil waste is one of the significant waste that should be more concerned because these waste is not easily biodegradable. It then leads to a serious ecological treat. By considering these two significant problems, a new alternative solution should be taken into consideration to minimize the cost of UHPC production and also minimize the environmental degradation. Thus, utilization of palm oil clinker (POC) in UHPC will be such a good alternative solution to overcome these upcoming issues. POC is a by-product of the incineration of palm oil shells. It is a light, solid, and fibrous material that can be used in crushed concrete. The elimination of steel fibres thus are being occupied by presence of POC in UHPC. The limitation knowledge in bond performance between UHPC and waste product as material replacement. The dominant UHPC in market are proprietary is coarse aggregate or gravel. UHPC require large amount of coarse aggregate in the production of UHPC. It will be a promising solution to incorporate POC as a replacement for coarse aggregate in UHPC. It not only reduces cost and minimize the degradation, but it also guides to sustainable development by ensuring the conservation of natural sources

The material producing UHPC provides compressive strengths up to 150 MPa. In the last decades, a lot of effort has been made to improve mechanical properties of UHPC. For example, most recently some waste materials were investigated as a new additive to UHPCs (Y.Su, 2016; C.Wu, 2017). However, fire or high temperature is still a great threat to all kinds of concretes including UHPCs. Therefore, an experimental studies should be done to investigated the strength of plain UHPC and also UHPC incorporating natural raw materials subjected to high temperatures.

1.3 Objective Of Study

The aim of this study is to investigate the possibility of using palm oil clinker (POC) as aggregate replacement in ultra-high performance concrete (UHPC). The objectives of study are as follows:

i. To determine the compressive strength of UHPC incorporating POC as aggregate replacement at different elevated temperatures.

ii. To observe the mode of failure of UHPC incorporating POC as aggregate replacement.

iii. To determine the optimum mix proportion and temperature of UHPC incorporating POC.

1.4 Scope Of Study

This study was focused on the investigated of the ultra-high performance concrete (UHPC) containing different percentages of palm oil clinker (POC) as aggregate replacement. The limitation of the this study was to investigate the durability of POC in terms of compressive strength and strength loss. Four (4) different percentages of levels POC as aggregate replacement were prepared. There are 0 %, 5 %, 10 %, and 15 % of POC from the total weight of aggregate. The UHPC and a series of POC-UHPC were labelled as plain-UHPC, POC-UHPC5, POC-UHPC10, and POC-UHPC15 respectively.

The constituent materials used for control mix in this present study were compromised of Ordinary Portland Cement (OPC), coarse aggregate, sand, water, and superplasticizer. In this study, the POC used was supplied by Kilang Sawit Felda Lepar Hilir, Gambang, Pahang. The nominal size of POC and coarse aggregate are 5 mm, while nominal size of sand is 300 µm. Sieve analysis test was done in accordance to BS EN 933-1:1997 to determine the particle size distribution of coarse aggregate, sand, and POC. A sufficient amount of each constituent material was weighed accordingly to the total raw materials required for the preparation of plain UHPC and a series of POC-UHPC specimens. The water cement (w/c) ratio was kept constant as low as 0.2. The percentage amount of superplasticizers included in all UHPC mixtures was constant at 3 % of cement weight.

In order to prepare the UHPC specimens, a total number of 144 cubes with dimensions of 100 mm x 100 mm x 100 mm were prepared. The specimens were cured in water tank for 7, 28, and 60 days. In the end of curing, the specimens were carried out and kept in furnace with various temperatures (200, 400, 600, 800°C) for one (1) hour. After 24 hours, the specimens were carried out and subjected to compressive strength test. The test procedure for compressive strength test was done as follows to BS EN 12390-6:2009.

1.5 Significance Of Study

The significant of this research project is to develop ultra-high performance concrete (UHPC) incorporating palm oil clinker (POC) as the aggregate replacement. The aim of this research is to produce UHPC with high compressive strength and high workability when replace with 0%, 5%, 10% and 15% of POC as aggregates replacement in UHPC. This research also evaluate the variations of compressive strength of UHPC at different elevated temperatures. The mode of failure of UHPC specimens also observed. At the same time, figures out the effects of palm oil clinker and elevated temperature towards UHPC.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter was reviewed in details the definition of UHPC, development of UHPC, application of UHPC, UHPC compositions and properties of UHPC. The detail explanations were presented in the following sections.

2.2 Ultra-High Performance Concrete (UHPC)

This sub-chapter was reviewed in details the definition of UHPC, development of UHPC, application of UHPC, UHPC compositions and properties of UHPC.

2.2.1 Definition of UHPC

Ultra-high-performance concrete (UHPC) is a novel construction material with enhanced mechanical and durability properties that can lead to cost-effective construction by reducing cross-sections of structural members with associated material savings and lower installation and labor costs (Tang, 2004). Ultra high performance concrete is a type of concrete exhibiting high strength and durability made up of binders such as Portland cement with a low w/c ratio, micro fillers for increasing the packing density, fine-grained sand, silica fume, a high range water reducing admixture to maintain the workability at low w/c ratio, coarse aggregates less than 5mm and small discontinuous steel fibers incorporated in the mix to overcome the brittle behavior of concrete.

UHPC is a relatively new generation of very high strength, ductility and durability cemented material (Richard, 1995). UHPC was defined by the French Interim Recommendations (AFGC, 2002) as a concrete with a compressive strength characteristic of at least 150 MPa using steel fiber reinforcement to ensure ductile behavior under tension. UHPCs with 130 MPa – 150 MPa compressive strength reinforced with either steel or other fibers are considered as UHPC lower strength.

The term UHPC is normally used to describe a fiber-reinforced, superplasticized, silica fume-cement mixture with a very low water-to-cement ratio (W/C), characterized by the presence of a very fine quartz sand that ranges from 0.15 to 0.60 mm in diameter, rather than the ordinary aggregate. In fact, due to the absence of coarse aggregate in the mixture, some researchers suggested that UHPC is not a concrete (Sadrekarimi, 2004; Sujatha, 2014). However, the term ' concrete ' is chosen to describe UHPC added with fine steel fibers to enhance ductility rather than ' mortar' (M. Couture, 1999; P. Aitcin, 2000; G. Ye, 2011).

UHPC has become increasingly interested in many countries over the past two decades, with use ranging from building components, bridges, architectural features, repair and rehabilitation, vertical components such as windmill towers and utility towers for applications in the oil and gas industry, offshore structures, hydraulic structures and overlay materials (Voo and Foster, 2017). This is because Ultra-High Performance Concrete (UHPC) is an advanced construction material with high strength and excellent durability. It offers the possibility of becoming a practical solution to improve the sustainability of buildings and other components of infrastructure (Schmidt and Fehling, 2015). Moreover, UHPCs have a discontinuous pore structure that reduces liquid ingress and permeability (Graybeal, 2011), leading to significantly enhanced durability, longer service life and lower costs for maintenance.

2.2.2 Development of UHPC

Concrete is the world's most popular man made material, the basic building material that will remain in demand far into the future. Global concrete production is estimated to be around 6 billion cubic meters per year, with China currently consuming about 40% of the world's concrete production (O.A.U. Uche, 2008; M. Malesev, 2010). High-quality concrete such as strength and durability, the ability to place it in many forms, and its low price have made concrete the most famous and important material in the building industry. For its strong compressive strength, concrete is mainly used (Cargile, 2001). Over the last decades, large progress has been taking place on the field of concrete development. Intensive research efforts began in 1930s to improve concrete compressive strength. Figure 2.1 shows the significant concrete technology achievements for the last 40 years (A. Spasojevic, 2008).

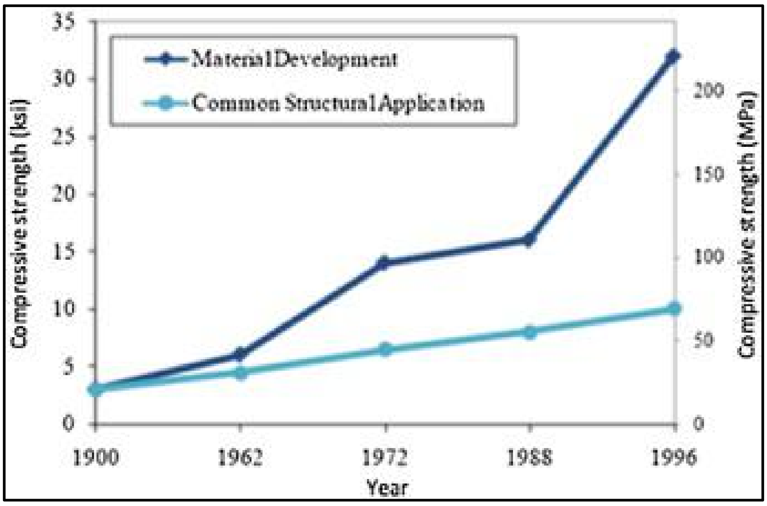

Figure 2. 1 The development of concrete compressive strength for over 100 years
Source: A. Spasojevic (2008)

From the graph, it can be seen that the concrete technology progressed slowly during the 1960s with the maximum compressive strength of 15 MPa to 20 MPa. The concrete compressive strength tripled to 45 MPa to 60 MPa over a period of about 10 years. Concrete strength reaches its plateau at about 60 MPa in early 1970s believed due to the technological barrier of the existing water reducer. The available water reducer at that particular time failed to reduce the water to binder ratio (W/B) any further (P.Aitcin, 2000). During 1980s, it is realized that the high-range water reducers, called superplasticizers (SP), can be used to progressively reduce W/B down to 0.30. Reducing the W/B below this was considered a taboo until Bache (1981) reported that, with high dosage of SP and silica fume (SF), it was possible to reduce W/B to 0.16. Concrete compressive strength of up to 280 MPa was achieved through compacted granular materials by optimizing the grain size distribution of the granular skeleton. These resulted in the creation of a material with a minimum number of defects, such as micro cracks and interconnected pore spaces, to achieve ultimate strength and durability enhancement.

2.2.3 Application of UHPC

UHPC has become increasingly interested in many countries over the past two decades, with use ranging from building components, bridges, architectural features, repair and rehabilitation, vertical components such as windmill towers and utility towers for applications in the oil and gas industry, offshore structures, hydraulic structures and overlay materials (Y.L. Voo, 2017). Among all these applications, road and bridge constructions are the most popular for UHPC application (GVR, 2017). A full search of the literature identified over 200 bridges built using UHPC in one or more of their components (Y.L.Voo, 2017). Other applications of UHPC can also be seen in buildings, structural strengthening, retrofitting, precast elements and some special applications (Suleiman, 2008; Resplendino, 2013). Both private and governmental bodies are currently turning their attention and initiative towards utilizing UHPC as the future sustainable construction material.

UHPC's advanced mechanical characteristics and durability allow for the reconsideration of conventional design methods for many common bridge components. Several research projects on optimal designs with UHPC elements were conducted and the UHPC bridges were developed and built worldwide. In 2002, the South Korean Seonyu footbridge was built on a 120 m main UHPC and finished in 2004 (K.C.Lee, 2003). The construction of the Seonyu footbridge was the world's longest span bridge made using UHPC and required approximately half the material quantity used in traditional concrete building while still providing the equivalents of strength (Y.L.Voo, 2003). UHPC was also interested in building components like sunshoes and coverings, as well as in roofing parts over the past decade. Due to its ability to make slender, lightweight, durable or esthetic buildings, UHPC was selected. Among the latest buildings adopting UHPC technology is the Foundation Louis Vuitton pour la Creation in Paris. Completed in 2014, this project is characterized by its high geometric complexity (Zdeb and Aubry, 2013).

UHPC was also used as an overlay for the reparation of existing concrete structures and for the improvement of its mechanical and durability properties for less maintenance work due to its excellent properties (Hajar and Moreillon, 2013). A bridge over the La Morge river in Switzerland reported the first application on the UHPC overlay. A UHPC has replaced the badly damaged bridge deck and curbs. After 1 year of application there were no cracks on the UHPC prefabricated curb. The successful repair and rehabilitation of these materials has paved the way for similar technology for deteriorating bridges. UHPC has great performance due to its wide range of applications, but many have yet to be found to use increased strength, durability and bending capabilities. In areas where is at risk, UHPC is offering economical and innovative solutions. UHPC is the building material for the future, it remains here and will grow worldwide continuously.

Table 2. 1 Example application of UHPC around the world

Application	**Location**	**Completion year**	**Compressive strength (Mpa)**
Sherbrooke footbridge	Sherbrooke, Canada	1997	200
Joppa clinker silo	Illinois, USA	2001	220
Seonyu footbridge	Seoul, Korea	2002	180
Sakata Mirai footbridge	Sakat, Japan	2002	238
Shepherds creek bridge	Sydney, Australia	2005	180
Blast resisting panels	Melbourne, Australia	2005	160
Whiteman Creek bridge	Brantford, Canada	2011	140
Sewer pipes	Germany	2012	151
Spun concrete columns	Germany	2012	179
UHPC truss footbridge	Spain	2012	150

Source: Schmidt et al. (2004, 2012), Fehling et al. (2008) and Talebinejad et al. (2004)

2.3 UHPC Composition

In the production of UHPC, the micro and macro characteristics of its mixture ingredients are improved, ensuring mechanical homogeneity, maximum particles and minimal flaw size (Schmidt et al., 2005; Vernet, 2004; Shah and Weiss, 1998; Wille et al., 2011; Shi et al., 2015). Table 2.2 shows the range of UHPC components for successful production of UHPC used in various studies. Data collected from Schmidt et al. (2004, 2012), Fehling et al. (2008) and Talebinejad et al. (2004).

Table 2. 2 Typical composition of UHPC

UHPC constituents	Range (% by weight)
Cement	27 - 40
Silica fume	6 - 12
Quartz	7 -14
Sand	35 - 45
Superplasticizers	0.5 - 3
Water	4 - 10
Steel fiber	0 - 8

Source: Schmidt et al. (2004, 2012), Fehling et al. (2008) and Talebinejad et al. (2004)

2.3.1 Cement

The proportion of cement used in UHPC is relatively large compared with normal (NS) and high performance (HPC) (Schmidt and Fehling, 2005; Ghafari et al., 2015). It has been shown that increasing the cement content increases UHPC's compression resistance; however, compressive strength is probably decreasing over and above its optimum cement content (around 1700 kg / m3 (106 lb / ft3), due to limited participation by aggregates (Talebinejad et al., 2004). A cement with moderate fineness of black (4000 cm2/g (281,240 in2/lb) and three-calcium aluminum (C3A) is preferred for the low demand of water (Wille et al., 2011). In addition, Strunge and Deuse (2008) have been used for developing UHPC special micro-fine cements of particle dimensions smaller than normal Portland cement.

The extremely low water-binder ratio (w / b) of UHPC enables the substituting of crushed quartz, fly ash and blast furnace slag for the total cement hydrates and unhydrated cement. For example, cement can be substituted in UHPC mixtures up to 30, 36 and 40 percent by volume, without compromising on compression strength, for crushed quartz, blast slag and fly ash respectively (Ma and Schneider, 2002; Soutsos et al., 2005; Yazici, 2006).

Adding silica fumes as binder can also improve the workability of UHPC by filling voids among coarser particles because of their much smaller particle size and an optimal spherical form. In addition, Silica Fume also strengthens UHPC by its pozzolanic response to this microfiling effect (Ma and Schneider, 2002; Cheyrezy and Richard, 1995). A number of studies by Ma and Schneider (2002) ; Matte and Moranville (1999) ; Chan and Chu (2004) ; Xing et al. (2006) recommended silica fume doses in UHPC for the denser particle packing and pozzolanic reactivity of 20-30 percent of total binder material, resulting in higher strengths. As an optimal dosage, 25 per cent (< 0,5 %) of low-carbon cement weight in UHPC has been recommended by Wille et al. (2011).

2.3.2 Aggregates

In general, failure of conventional concrete is due to damage between the cemented matrix and aggregates within an interfacial transition zone (ITZ) (Jun et al., 2008). The removal of coarse aggregates from UHPC mixtures reducing the weaknesses caused by the ITZ. Moreover, mitigation of ITZ flaws generally lead to lower matrix porosity and increased mechanical strength (Mehta et al., 2006). Because of the formation of interfacial transition zone and weak mechanical properties, the larger aggregates are excluded (Cwirzen et al., 2006). The effect of the various sands and coarse aggregate on mixed properties was explained in a detailed experimental programme, conducted by Sobuz et al. (2016). The results demonstrated an opposite relationship to the compressive strength of the mix. Fine aggregates such as quartz sand are an important factor in reducing the maximum paste thickness (MPT), which is also an important factor in the UHPC mix design. For a quartz particle size of 0.8 mm (0.031 in), the optimal sand to cement proportion was found to be 1.4 (Wille et al. 2011).

2.3.3 Water-Cement (w/c) Ratio

The UHPC mixtures have very low water/cement ratio (w/c). Richard and Cheyrezy (1995) reported at least w/c ratio of 0.08 but that ratio did not guarantee dense packing of particles. In previous studies, an optimal w/c ratio of 0.13–0.20 has been suggested in order to achieve a maximum relative density and spreading flow (Richard and Cheyrezy, 1995, Larrard and Sedran, 1994, Gao et al., 2006, Wen-yu et al., 2004, and Shi et al., 2015). However, researchers have also achieved greater compressive strength than 150 MPa (22 ksi) in use of 0.25 w/c ratio (Wille et al., 2011; Droll, 2004). It can be argued that w/c ratio is not the only force controlling UHPC parameter. The important parameters included are curing regime, mixture ingredients properties, mixing procedures and mixer type.

2.3.4 Superplasticizers

To achieve the required workability of the UHPC mix, high-range water reducing admixture is needed. Superplasticizers improve the workability of the mix at a low water-to-cement relationship. This means that UHPC has a very low water/cement ratio that it is necessary. Ma et al. (2008) have been working on the effect of additioning superplasticizers in UHPC. In this study, adding superplasticizers gradually reduces the mixture's viscosity and enhances the mix's workability. The late addition of the second section showed that this increase in the cement characteristics with high activity index. They proposed the combination of concrete and superplasticizers for which time such as cement, which is hydrated slowly, will not influence the addition of superplasticizers.

The dosage required for superplasticizers is significantly dependent on the mixture compatibility with the type of superplasticizers. Better compatibility may result in lower doses of superplasticizers. The UHPC blend with a limestone micro-filler is more workable and compatible than the mixture with the same superplasticizers incorporating greater surface metakaolin (Rougeau and Burys, 2004). In addition, it was found that gradually or delayed addition of superplasticizers (instead of adding the superplasticizers simultaneously) improved workability of UHPC mixtures due to an improved dispersing effect (Tue et al., 2008). Several studies have used superplasticizers dosages ranging between 1 and 8 % of cement weight for improving the working ability of UHPC mixtures (Schmidt et al., 2004, 2012; Fehling et al., 2008). Superplasticizers dosage is generally recommended to be 1.4–2.4 percent by cement weight (Wille et al., 2011).

2.3.5 Supplementary cementitious materials

Supplementary cementitious materials (SCM) are used in UHPC for partially replacing cement to make the mix cost effective. SCMs that have been used to replace cement in UHPC is palm oil clinker (POC). Recent practices has shown a decrease in the use of clinker in cement from 85 to 77 % and is subjected to a further decrease in the future (Schneider et al., 2011). The replacement of cement content in UHPC can be even more environmentally friendly. Randl et al. (2014) stated that, while taking into consideration the environmental point of view, reduced member size for UHPC is a further benefit from NSC. The research suggested that SCMs can replace up to 45% of cement, without significantly affecting mechanical properties.

Then, Kanadasan and Abdul Razak (2015) study revealed that incorporating POC in concrete can save cost, reduce carbon emission and energy consumption. Mohammed et al. (2014) reported that Oil Palm Shell (OPS) and Oil-Palm-Boiler Clinker (OPBC) are used as an alternative lightweight aggregate (LWA) in tropical regimes and countries that have a palm oil industry. POC is a waste material from agricultural sector resulting from the incineration of palm oil shell in the form of light solid fibrous material. POC is available in the form of solid lightweight material in varying sizes between 20 and 150 mm. Typically, POC is obtained in a large chunk and it is porous in nature with a sharp and rough broken edges, and often flaky with an irregular shape as shown in Figure 2.2. POC serves as possible aggregates in the production of concrete when crushed to required size (Abutaha et al., 2016, Ibrahim et al., 2017 Ibrahim et al., 2017).

Figure 2. 2 Palm oil mill waste

2.4 Properties of UHPC

The properties of UHPC was focused on the compressive strength of UHPC in terms of effect of palm oil clinker and effect of elevated temperatures.

2.4.1 Compressive Strength

2.4.1.1 Effect of Palm Oil Clinker

The POC concrete and OPC consist of a mixture of inorganic oxides and the particle size is also similar. The particles of POC concrete are irregular in size and contained numbers of micro pores. The relative residual compressive strength of OPC and POC concrete are almost similar due to the dilution effect and acceleration of the hydration reaction when treated at 300 °C. The relative residual compressive strength of OPC was lower than POC concrete primarily due to mainly pozzolanic reactionof POC concrete when treated at elevated temperature. The decomposition of the hydrated product of OPC was occurred at low temperature compare to POC blended cement that an indicating better high fire resistivity. The POC concrete is more condensed in structure due to C-S-H which was filled micro pores of matrix that ultimately developed the compressive strength.

2.4.1.2 Effect of Elevated Temperatures

UHPC structures can be more vulnerable to fire and elevated temperatures due to its reduced porosity, which hinders the release of vapor pressure, leading to physical damage (Way and Wille, 2012). However, the use of polypropylene (PP) fibers can mitigate this issue. Various studies (Schmidt et al., 2004; Heinz et al., 2004) showed that the addition of 0.6 % by mixture volume of PP fibers improved the fire resistant properties (prevented spalling) of UHPC since melting of the PP fibers at high temperature creates space to release the build-up of pressure. However, cracks [0.3−0.5 mm (0.012−0.020 in)] were observed at the specimen's surface. Furthermore, disintegration of UHPC mechanical properties was observed due to dehydration of calcium silicate hydrate products, chemical decomposition of UHPC materials and thermal expansive damage (Way and Wille, 2012; Pimienta et al., 2012). It was observed that UHPC with 0.6 % PP fibers by volume mixture achieved weight loss of less than 9 % at 1000 °C (1832 °F) (Heinz et al., 2004).

Moreover, Tai et al. (2011) reported an increase in compressive strength of UHPC specimens heated up to 300 °C; however, a decreasing trend in compressive strength was observed beyond 300 °C. A declining trend in mechanical properties of UHPC at elevated temperature was mainly due to the weakening of internal microstructure (Li and Liu, 2016). An improved behavior at elevated temperature was observed with the addition of steel fibers in UHPC specimens (Tai et al., 2011; Li and Liu, 2016; Zheng et al., 2012).

2.5 Palm Oil Clinker

Malaysia is one of Asia's main palm oil producers. It is the world's second largest palm oil producer and produces annually more than half the world's palm oil. The palm shell of Malaysia is expected to grow as a waste of approximately 3.13 million tons, due to the continuing demand of global palm oil consumption. The palm oil industry, with an annual production of 2.6 million tons of solid waste, is also an important contributor to the pollution problem in the country (H. Basri, 1999). The high amount of waste generated is mostly composed of palm oil clinker (POC) and palm oil shell. POC is abundant and have small commercial value in Malaysia;hence, this industrial waste can be converted into potential construction materials. POC is a by-product of the incineration of the palm oil shell. It is a lightweight, solid and fibrous product, which can be used for crushed concrete as a possible lightweight aggregate. A previous research by Kanadasan and Abdul Razak (2015) showed that utilization of POC reduces the costand energy usage and lowers carbon emission. he feasibility study performed on POC aggregates confirms theability of POC to reduce the density of the mortar by 7% to produce structural efficiency between 0.035 and 0.05 MPa/kg m^3 (J.Kanadasan et al., 2015). Abdullahi, Al-Mattarneh (2008) studied the trial mix proportions for POC concrete to accurately determine the properties of POC aggregate such as particle size distribution, specific gravity, and water absorption. It was shown that utilization of POC aggregate in the mix design of concrete is possible without any admixture. Despite replacing cement with 50% of POC powder, almost 70% of the strength can be achieved compared to conventional mortar (J.Kanadasan et al., 2015).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter was described in details the procedures that carrying out on the experimental works to achieve the objectives of study. The methodology was drawn to ensure the study in line with the scope of study. The summary of the experimental process flow for plain - UHPC and series of palm oil clinker were outlined in Figure 3.1.

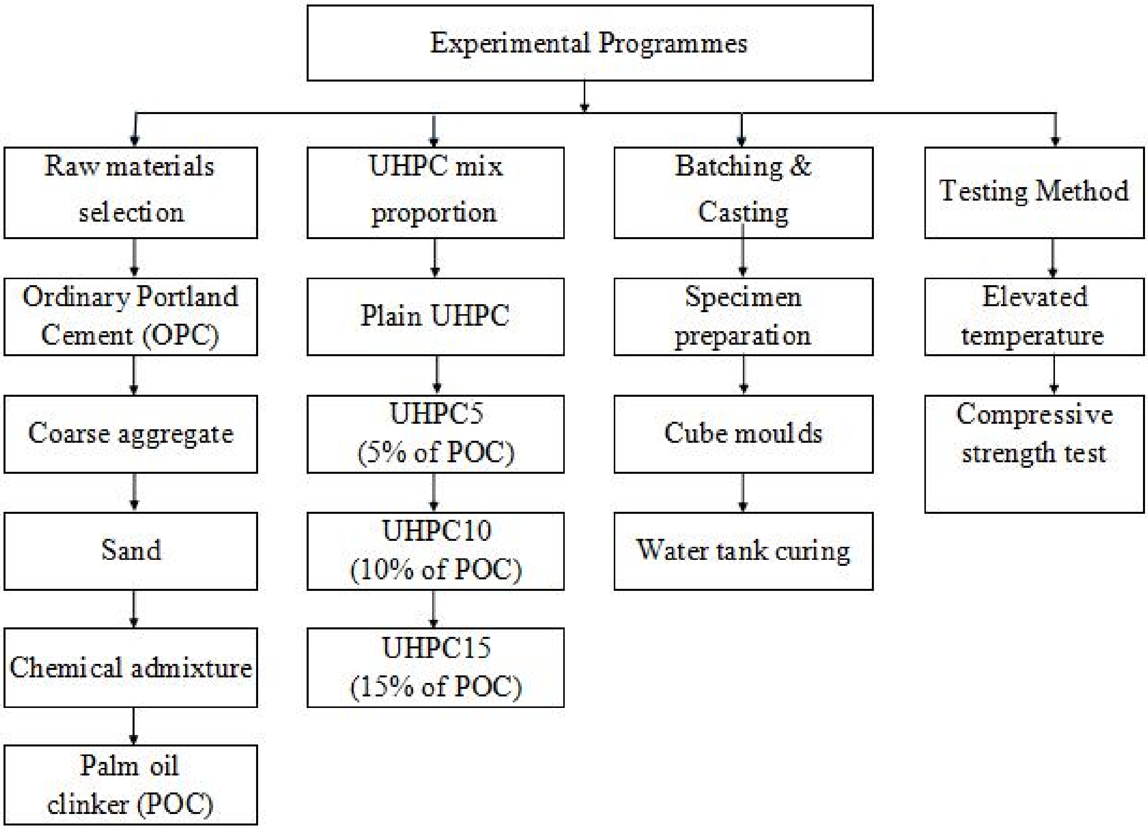

Figure 3. 1 Flow-chart process for experimental programme

3.2 Raw Materials Selection

3.2.1 Ordinary Portland Cement

Ordinary Portland Cement (OPC) Type 1 provided by local supplier was used in this present study as a binder to produce plain UHPC and a series of UHPC incorporated POC mixtures. The properties of OPC are equivalent to BS EN 197-1 : 2000 specifications. Sufficient amount of cement was procured and stockpiled safely to prevent hardening of cement. High amount of cement content was employed in this study. The cement content was constant at 800 kg/m^3 for all series of mix proportion of plain UHPC and a series of POC-UHPC mixtures. Figure 3.2 displays the ordinary portland cement (OPC) Type 1 used in this study.

Figure 3. 2 Ordinary Portland Cement (OPC**)**

3.2.2 Coarse Aggregate

Aggregate and sand act as inner filler within a concrete mix. The function of aggregate remains same even though the formulation of UHPC are differ from conventional concrete. The performance of concrete mix depends on the gradation, maximum size, unit weight and moisture content of aggregate. Some of UHPC formulations had been eliminated the use of coarse aggregate. However, coarse aggregate are sometimes included in UHPC formulations but the size of aggregates tend to be relatively small. The proportion of coarse aggregate also must be kept low compared to conventional concrete.

Therefore, the natural crushed gravel was used as the coarse aggregate with a nominal size of aggregates must passing 5mm and retained on 5mm and retained 2.36mm sieve as shown in Figure 3.3. The particle size distribution of coarse aggregate was determined from sieve analysis. BS sieve ranging from 14mm to 160μm were used to conduct the sieve analysis. Figure 3.4 displays the particle gradation curve of natural crushed gravel conformed to the requirement as per BS EN 933-1:199.

Figure 3. 3 Natural Crushed Gravel with nominal size of 5mm

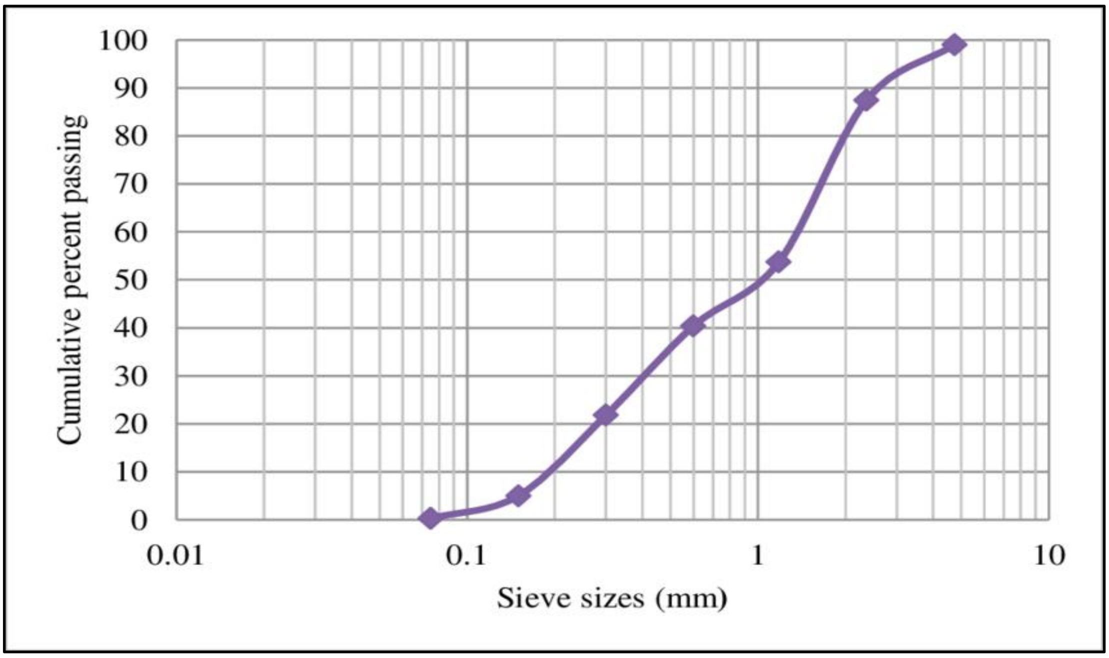

Figure 3. 4 Particle size distribution of natural crushed gravel

3.2.3 Sand

In this study, natural river sand is generally used as fine aggregate with a nominal size of 5 mm and retained on 300 μm sieve was used as shown in Figure 3.5. the sieve analysis test was conducted to determine the particle size distribution of natural river sand. The test was carried out based on BS EN 933-1:1997. BS sieve ranging from 5 mm to 300 μm were used to conduct the sieve analysis. Figure 3.6 illustrates the particle distribution curve of natural river sand used in the mix proportion of a series of plain UHPC and POC-UHPC mixtures.

Figure 3. 5 Natural river sand with nominal size of 300μm

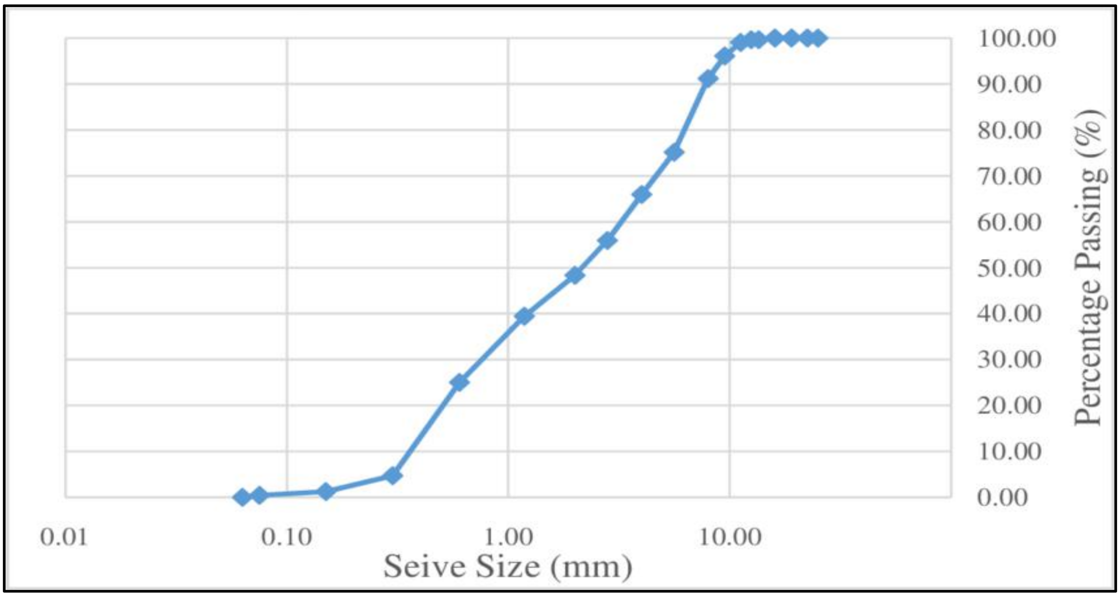

Figure 3. 6 Particle size distribution of natural river sand

3.2.4 Water

In UHPC mixtures, a very low amount of water content was required. For this study, tap water was used for mixing and curing for all series of plain UHPC and POC-UHPC. Water that must be ensured to be in clean and free from impurities position. This is because it will affect the process of hardening, volume stability, durability and discoloration.

3.2.5 Chemical Admixture

Graybeal (2011) reported that chemical admixture (CA) commonly include accelerator, polycarboxylate-based superplasticizer and phosphonate-based superplasticizer. The use of chemical admixture namely superplasticizers (SP) in UHPC mixes permits fluid mixes with a very low water-cement (w/c) ratio. The resulting concrete has a very high strength and density, and a very low porosity (Tuan, 2011).

The water cement (w/c) ratio used in this study for all the series mixtures was constant at 0.20. Therefore, chemical admixture is vital component to be employed in all UHPC mixtures to permits fluid mixes with such very low w/c ratio. The High Range Water-Reduce (HRWR) admixture for early strength namely Sika ViscoCrete 2008 PC was used in this study. The chemical base of the HRWR admixture is modified polycarboxylate type. The dosage of HRWR admixture used are 3 % from the total of cement materials for a plain UHPC and POC-UHPC mixtures.

3.2.6 Palm Oil Clinker

Palm oil clinker (POC) is a waste material produced as result of using palm oil shell and mesocarp fibers as fuel to run stream turbines in palm oil mills. The current practice is to dump this waste in open land or landfill sites, which leads to environmental problems. The characterization of such waste to identify its suitability as a cement replacement materials, can ultimately lead to lower carbon footprint concrete. The POC was supplied by Kilang Sawit Felda Lepar Hilir, Gambang, Pahang. It is used as a aggregate replacement. A total of 5 %, 10 % and 15 % of POC replacement from the total weight of sand to produce series of POC-UHPC specimens. The size for POC used in this study are same as the size of coarse aggregate which is 5 mm and retained on 2.36μm. The particle size distribution of POC was determined from sieve analysis in accordance to BS EN 933-1:1997. BS sieve ranging from 5mm to 160 µm were used to conduct the sieve analysis. Figure 3.7 and Figure 3.8 shown the particle size and the particle size distribution of of POC.

Figure 3. 7 Palm oil clinker with nominal size 5 mm

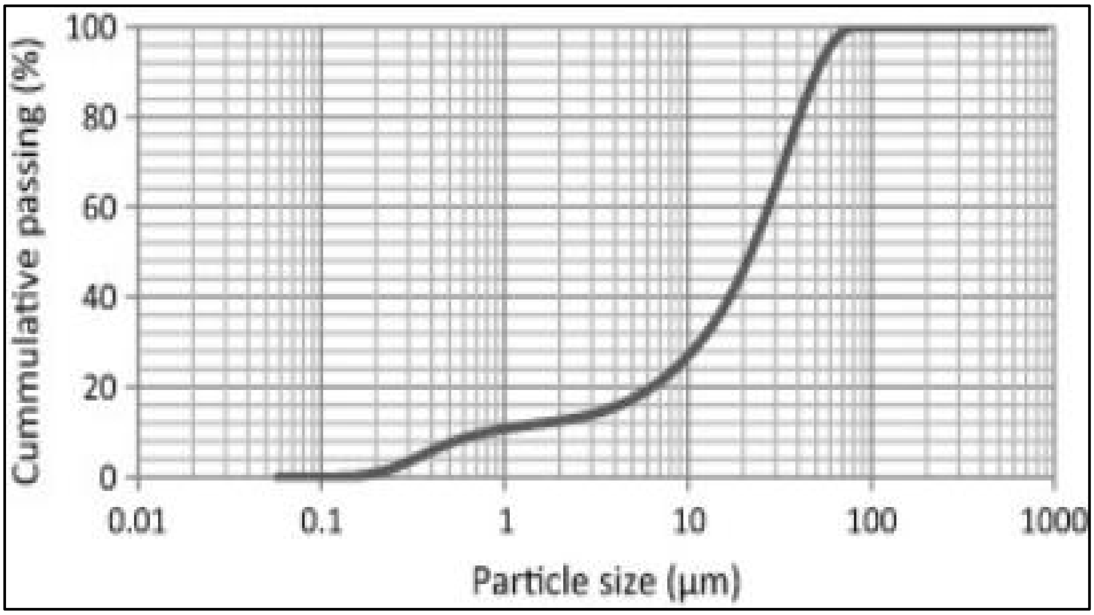

Figure 3. 8 Particle size distribution of Palm Oil Clinker

3.3 Mix Proportion Design

For this study, the mix proportion of a plain UHPC and POC-UHPC series were prepared. Plain UHPC was prepared as a normal UHPC mix without additioning palm oil clinker (POC). this mixture was designed as control mix. Meanwhile, 5 %, 10 % and 15 % of POC were used as partial aggregate replacement and was designed as POC-UHPC5, POC-UHPC10 and POC-UHPC15, respectively. These POC was consisted of 5 mm size same as coarse aggregate. An addition of chemical admixture known Sika ViscoCrete 2008 PC was employed in plain UHPC and POC-UHPC series as partial cement replacement. The water-cement (w/c) ratio used was constant at o.2. Table 3.1 tabulates the mix proportion for the plain UHPC and series of POC-UHPC mixes. The mix proportion of plain UHPC was adopted by Mohd Faizal (2016).

Table 3. 1 Mix proportion of plain UHPC and POC-UHPCs

Mix Designation	**Raw Materials (kg/m³)**						
	OPC	W/c	Coarse Aggregate	Sand	Water	CA	POC
Plain UHPC	880	0.2	433	800	160	32	0
POC-UHPC5	880	0.2	411.35	800	160	24	21.65
POC-UHPC10	880	0.2	389.70	800	160	24	43.30
POC-UHPC15	880	0.2	368.05	800	160	24	64.95

3.4 Preparation Of Specimens

In the preparation of UHPC specimens, the required amounts of the constituents materials such as Ordinary Portland Cement (OPC), additional OPC, chemical admixture, coarse aggregate, and sand were weighed properly according to the mix proportion as specified in Table 3.1. Sieve analysis test was done for aggregate, sand and palm oil clinker (POC) to determine particle size distribution of these raw materials. The POC was incorporated as partial replacement of aggregate. Concrete pan mixer was used for mixing process. The batching, mixing and casting process of the concrete specimens were discussed at the following sub-sections. Dimension of specimens and curing ages of the concrete specimens also were discussed.

3.4.1 Batching, Mixing And Casting

There are four (4) series of mix designation were prepared. There are plain ultra-high performance concrete (UHPC) and three (3) series of POC-UHPC with different percentages of palm oil clinker as partial replacement of aggregate. Plan UHPC was designated as control mix without any incorporation of POC. For the mixing process, concrete pan mixer was used as displayed in Figure 3.9.

During the mixing, the OPC and POC were mixed together with water until uniformly. Once the mix homogeneously, the High Range Water-Reduce (HRWR) admixture know as Sika ViscoCrete 2008 PC was added gently into the concrete pan mixer and mix continuously. The amount of HRWR used was kept constant at 3 % for all specimens. After the mix become cementt paste and flowability, coarse aggregate and sand were poured into pan mixer to mix until uniformly flowable together with cement paste. Once the mix become uniformly flowable, the concrete mixture was poured into cubes mould of 100 x 100 x 100 mm about (1/3) from the total volume of concrete mould. After that, the moulds were placed on vibrator table to compact the fresh concrete mix. The process was repeated for two (2) times for each mould. While vibrating the moulds, the excess materials on surface of the cube moulds were removed with a trowel. Then, the cube moulds was stored at dry area with the temperature room for about 24 hours before being removed for curing process as shown in Figure 3.10.

For the POC-UHPC mixtures process, it is similar to the process of plain UHPC. The different is after the cement paste is done, the POC with certain percentage was added and mix until the mixture become uniformly flowable. After that follow with poured into the cube moulds, vibrator, removed the excess materials on surface and store at dry area. The process was repeated with different percentage of POC. Figure 3.11 shows the procedure of pouring materials into pan mixer.

Figure 3. 9 Concrete pan mixer

Figure 3. 10 Cubic mould was stored in dry area for 24 hours after casting

Figure 3. 11 Pouring Material into concrete pan mixer

3.4.2 Curing Ages

All the concrete specimens were demoulded after hardened for 24 hours. The concrete specimens were kept in water tank for curing about 7, 28 and 60 days before subjected to compressive strength test. Figure 3.12 displays the concrete specimens in water tank for curing process.

Figure 3. 12 Specimens were cured in water curing

3.5 Testing Procedures

The testing method conducted had been focused on the strength properties of hardened specimens compromising of plain UHPC and three (3) series of POC-UHPC specimens. The strength properties was determined by conducting compressive strength test. Before undergoes the compressive strength test, the specimens were exposed to elevated temperatures of 200, 400, 600 and 800°C.

3.5.1 Elevated Temperatures

For this study, the specimens were stored in the furnace at various temperatures for one (1) hours. To use the furnace, the temperatures must be set up early in the morning as the temperature take time to rise. When the temperature was reach to current used temperature, set the timer for one (1) hours and lower the temperature as the timer is done. The specimens only can be pick up for the compressive test after 24 hours as the temperature need to be low to avoid any danger or consequences due to high temperature.

Figure 3. 13 Furnace for elevated temperatures process

3.5.2 Compressive Strength Test

Compressive strength test on UHPC specimens was conducted as per BS EN 12390-3:2009 on cubic specimens of size 100 x 100 x 100 mm. After 24 hours casting, the cubic specimens were taken out from the moulds. After demoulding process, the hardened specimens were kept in water tank for curing process at the ages of 7, 28, and 60 days. At the testing day, the specimens then were taken out from the water tank and being heated at various temperatures of 200, 400, 600, and 800°C in the furnace for one (1) hours. After done heated, the compressive strength test was conducted on the specimens by using an automatic compression testing machine with loading capacity of 1000kN. The compressive strength of concrete was evaluate at the ages of 7, 28, and 60 days. The maximum load and the maximum strength applied to the hardened specimens were recorded. The average readings of maximum strength for tested three (3) cubic specimens were recorded as the compressive strength of the specimens. Basically, the compressive strength was calculated by using Equation 3.2.

$$\text{Compressive Strength, Fc} = \frac{\text{Load (P)}}{\text{Cross Sectional Area (A)}} \tag{3.2}$$

Figure 3. 14 Compressive Strength Testing Machine

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter was discussed on the results of the strength properties in terms of compressive strength and splitting tensile strength. The performance from each type of testing were presented in form of tables and graphical.

4.2 Compressive Strength Test

This section discussed the results of compressive strength on cubic specimens in terms of curing ages and percentages of palm oil clinker (POC).

4.2.1 Effect of Different Temperature Subjected to Compressive Strength

Compressive strength test according to BS EN 12390-3-2009 was carried out on the cubic specimens of size 100 mm x 100 mm x 100 mm. The specimens were loaded at constant strain rate until failure. Tables 4.1 to 4.4 tabulate the results on compressive strength results of cubic UHPC specimens with different percentages of POC at different elevated temperatures. It was found that the compressive strength of plain UHPC and series of POC-UHPC specimens increased from 200°C to 400°C and began to decrease as the temperature rise above 400°C until 800°C. The comparison of compressive strength of cubic UHPC specimens at different curing ages are displayed in Figure 4.1 to Figure 4.4.

Table 4. 1 Compressive strength of cubic UHPC specimens at 200°C

Curing Ages	Compressive Strength (N/mm²)			
	Plain-UHPC	POC-UHPC5	POC-UHPC10	POC-UHPC15
7	73.72	76.73	68.45	66.45
28	84.75	99.29	93.87	83.37
60	74.57	74.11	70.57	56.43

Table 4. 2 Compressive strength of cubic UHPC specimens at 400°C

Curing Ages	Compressive Strength (N/mm²)			
	Plain-UHPC	POC-UHPC5	POC-UHPC10	POC-UHPC15
7	80.08	82.73	70.54	70.34
28	81.97	87.76	92.65	86.75
60	78.85	74.23	91.00	77.43

Table 4. 3 Compressive strength of cubic UHPC specimens at 600°C

Curing Ages	Compressive Strength (N/mm²)			
	Plain-UHPC	POC-UHPC5	POC-UHPC10	POC-UHPC15
7	63.72	60.80	66.60	69.94
28	69.11	69.06	70.84	69.07
60	65.04	59.06	74.16	67.79

Table 4. 4 Compressive strength of cubic UHPC specimens at 800°C

Curing Ages	Compressive Strength (N/mm²)			
	Plain-UHPC	POC-UHPC5	POC-UHPC10	POC-UHPC15
7	46.73	41.47	36.03	45.46
28	49.60	43.85	43.20	49.24
60	53.25	45.09	39.99	40.07

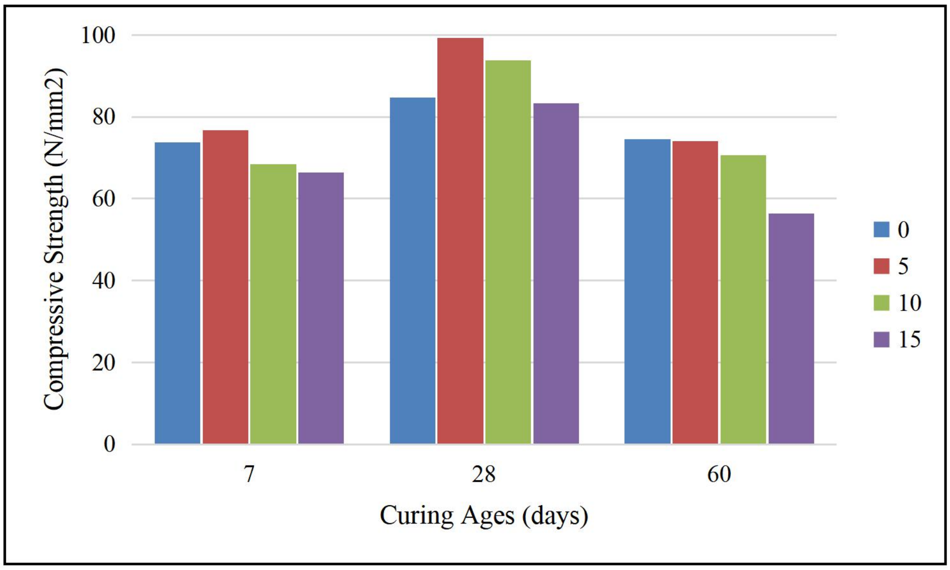

Figure 4. 1 Comparison of compressive strength of cubic UHPC specimens at different curing ages for 200°C

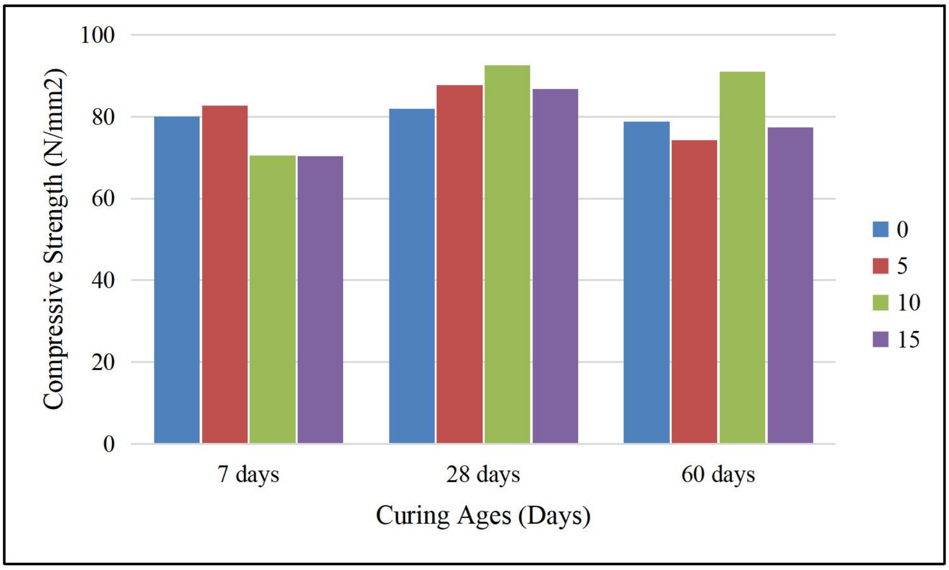

Figure 4. 2 Comparison of compressive strength of cubic UHPC specimens at different curing ages for 400°C

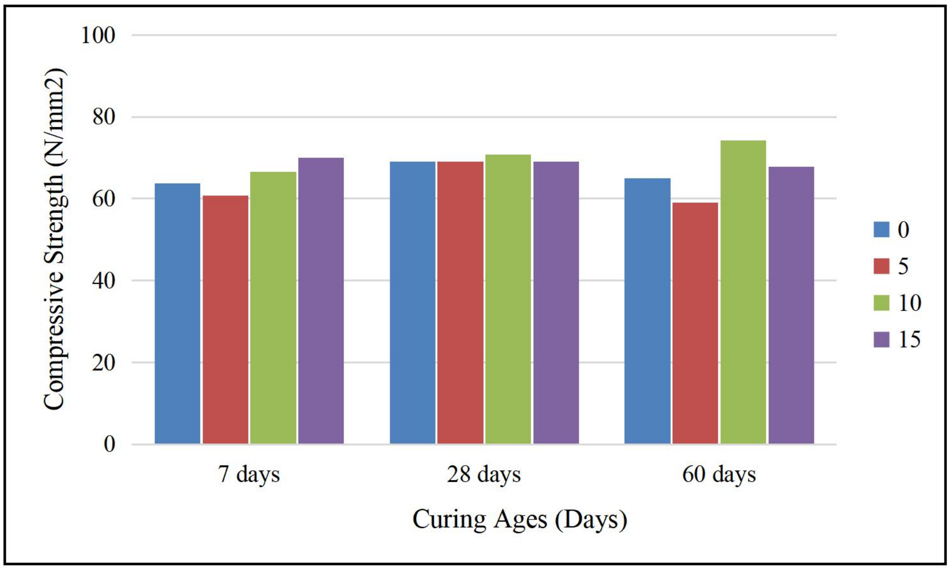

Figure 4. 3 Comparison of compressive strength of cubic UHPC specimens at different curing ages for 600°C

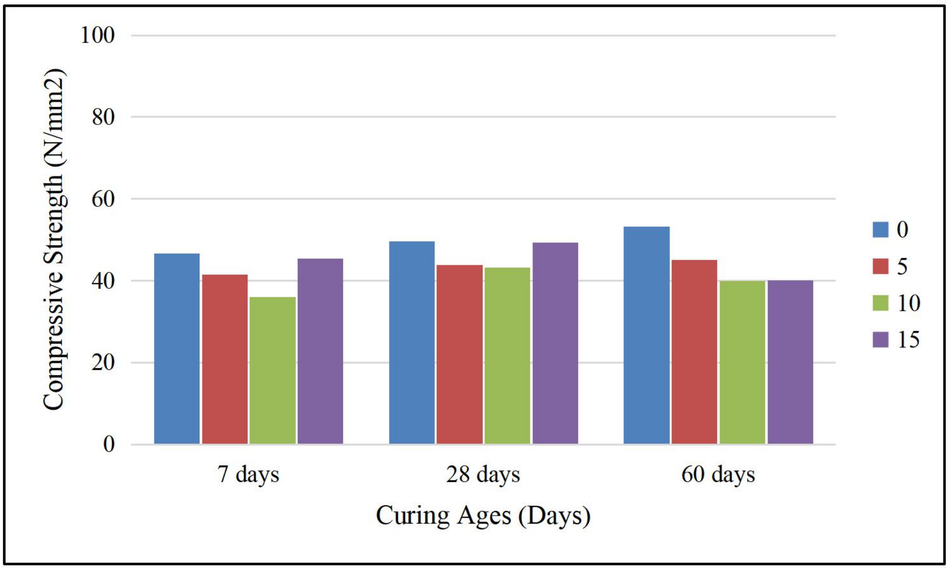

Figure 4. 4 Comparison of compressive strength of cubic UHPC specimens at different curing ages for 800°C

As shown in Figure 4.1 to Figure 4.4, it can be observed that the compressive strength of the plain-UHPC and series of POC-UHPC specimens increased as the temperatures rises from 200°C to 400°C and decreased as the temperatures keep increases up to 800°C. From 200 °C to 400°C, the UHPC concrete having early strength and increase until 28 days of curing. After that, the UHPC concrete loss in strength as the curing ages increases as well as temperatures.

In contrast, from 400 °C to 800 °C all the concretes suffered a strength decrease. It can be seen from Figure 4.2, the strength loss of the POC-UHPC10 concrete was a little steeper than that of the POC-UHPC5 concrete, while the POC-UHPC15 and Plain-UHPC concrete had a much slower deterioration of strength than the other two. During this stage, decomposition of the CH occurred between approximately 430 °C and 600 °C, while for the C-S-H it started at around 560 °C and then became significant above 600 °C (Rashad et. al., 2012). A large amount of C-S-H was transformed into C3S and β-C2S and α-SiO2 was transformed into β-Si2O2, which resulted in increased porosity in the paste (H.Li et. al. 2012). At 800 °C, the C-S-H was completely decomposed and the CaCO3 started to decompose, contributing to decreased compactness of the internal structure and a lot of small cracks on the surfaces of the specimen. Also, at this stage, the mismatching volume expansion between the cement paste and the aggregate played a significant role that worsened the mechanical performance of the concrete (V.Ducman, 2011; D.Moric, 2013).

Zhu Chen (2018) studied that after exposed to 200 °C, the C-S-H phase in the concrete remained continuous and became more compact while the CH crystals became fewer and smaller. However, due to melting of PP fibre and cracking resulting from vapour pressure, the matrix presented a rougher surface. After subjected to 400 °C, the C-S-H phase had even more compact structure and better integrity while the CH phase continued to reduce in quantity and size. Suffering 600 °C, the C-S-H phase lost some continuity and integrity due to decomposition and became less compact. At the same time, the CH phase completely decomposed. At 800 °C, the C-S-H phase did not exist any longer and the matrix was honeycombed, resulting in greatly worsened concrete performance.

4.2.2 Effect of Different Percentages of Palm Oil Clinker Subjected to Compressive Strength

For this study, the results of the compressive strength of specimens at 7, 14 and 28 day for plain UHPC and series of POC-UHPC are presented in Tables 4.5 to 4.7. Meanwhile, the comparison of compressive strength of cubic UHPC specimens at different percentages of RTRW are displayed in Figure 4.2.

Table 4. 5 Compressive strength of cubic UHPC specimens at 7 days

Temperatures	Compressive Strength (N/mm²)			
	Plain-UHPC	POC-UHPC5	POC-UHPC10	POC-UHPC15
200	73.72	76.73	68.45	66.45
400	80.08	82.73	70.54	70.34
600	63.72	60.8	66.6	69.94
800	46.73	41.47	45.36	36.03

Table 4. 6 Compressive strength of cubic UHPC specimens at 28 days

Temperatures	Compressive Strength (N/mm²)			
	Plain-UHPC	POC-UHPC5	POC-UHPC10	POC-UHPC15
200	84.75	99.29	93.87	83.37
400	81.97	87.76	92.65	86.75
600	69.11	69.06	70.84	69.07
800	49.6	43.85	43.2	39.24

Table 4. 7 Compressive strength of cubic UHPC specimens at 60 days

Temperatures	Compressive Strength (N/mm²)			
	Plain-UHPC	POC-UHPC5	POC-UHPC10	POC-UHPC15
200	74.57	74.11	70.57	56.43
400	78.85	74.23	91.00	77.43
600	65.04	59.06	74.16	67.79
800	53.25	45.09	39.99	40.07

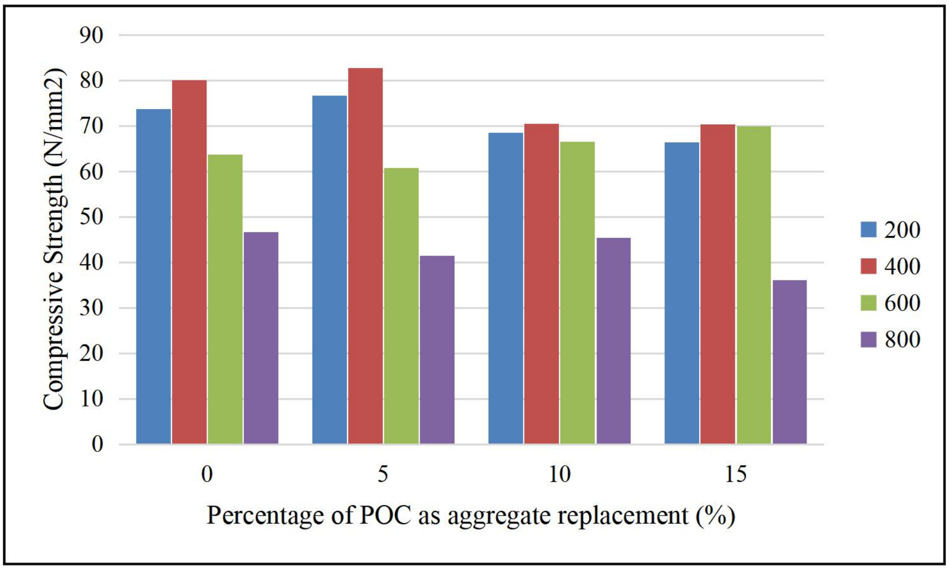

Figure 4. 5 Comparison of compressive strength of cubic UHPC specimens at different percentages of palm oil clinker at 7 days

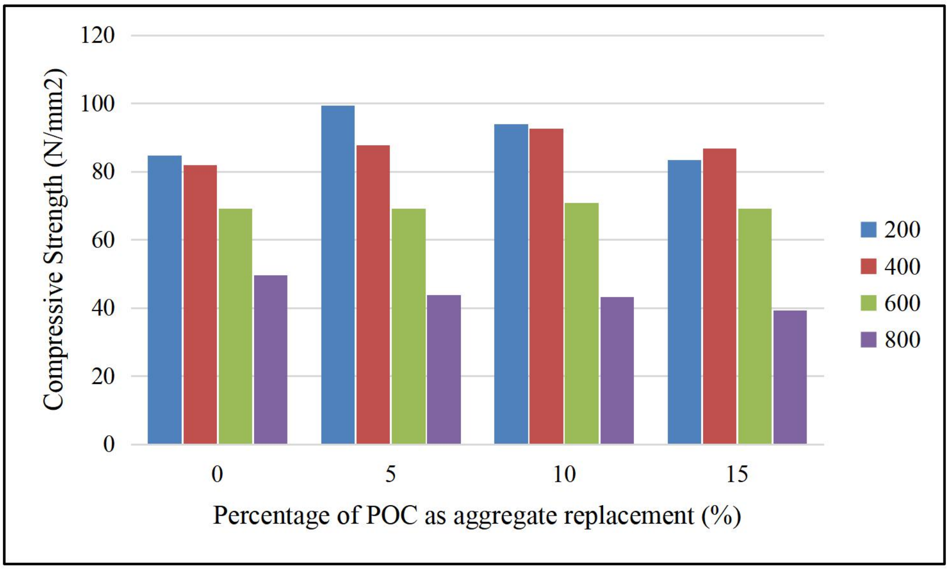

Figure 4. 6 Comparison of compressive strength of cubic UHPC specimens at different percentages of palm oil clinker at 28 days

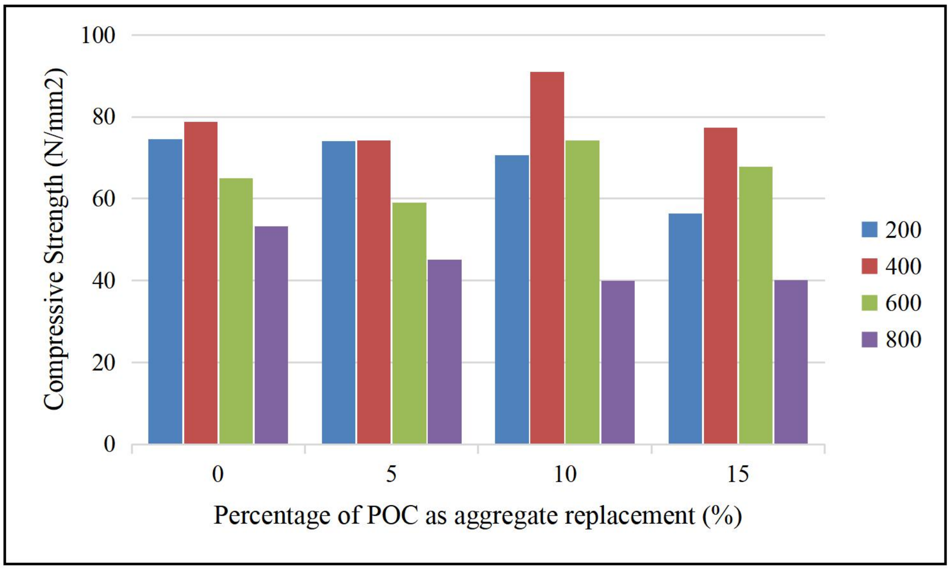

Figure 4. 7 Comparison of compressive strength of cubic UHPC specimens at different percentages of palm oil clinker at 60 days

It can be seen from Tables 4.5 to 4.7 that the highest compressive strength of cubes at 7 days is 82.73 N/mm2 for POC-UHPC5 at 400 °C. The result showed that the mix of UHPC incorporating 5 % of palm oil clinker exhibited better performance in terms of compressive strength as compared with other UHPC specimens. In line with the previous findings, the compressive strength was proved reduced when incorporating POC as partial replacement of aggregate into UHPC mixes.Similarly, the plain UHPC specimens at 14 days and 28 days exhibit the highest compressive strength as compared with UHPC incorporating of POC. The compressive strength of plain UHPC at 28 days is 84.75 N/mm2 and there is significant reduction for POC-UHPC10, and POC-UHPC15 respectively.

Meanwhile, there are also significant reduction in compressive strength at 60 curing days in comparison with the control mix at 28 days. When 5 % of POCwas used as aggregate replacement, there was reduction in compressive strength for 60 curing days. Meanwhile, the compressive strength was found increase when 10 % of POC as aggregate replacement. On the other hand, when 15 % of the aggregate being replaced by POC, there was the highest reduction at 60 days as compared to control mix. Thus, it can be concluded that the higher the percentage content of POC into the UHPC mix, the higher the reduction in compressive strength.

4.3 Mode of Failure

The mode of failure was observed during the compressive strength test and splitting tensile strength test. Figure 4.8 and Figure 4.9 illustrate the failure mode of plain UHPC and series of POC-UHPC concrete after failure in compressive strength test respectively at age of 28 days.

Figure 4. 8 Failure mode of plain UHPC cubic specimen

Figure 4. 9 Failure mode of POC-UHPC cubic specimen

Without addition of any POC, the plain concretes suffered brittle damage and were crushed up under either temperature. By contrast, the UHPC concrete incorporating palm oil clinker improved a lot in ductility and remained its integrity under the compressive loading. As can be seen, the POC-UHPC concrete suffered a ductile damage at temperature 200 °C, but under temperatures 400, 600 and 800 °C its damage was in a brittle manner. It was because the POC improved the ductility of the concrete under room temperature. However, when it was heated to 200 °C and above, the resulted shown a deterioration of ductility of the concrete. Under 800 °C, the POC-UHPC concrete exhibited a ductile failure mode again. This was because the concrete had been loosened and softened. Rashad et al.(2012) pointed out coarsening of pore-structure can happen when cement paste is heated to 400 °C and above and C-S-H can be dramatically decomposed at 600 °C and above, which may lead to concrete loosening and softening and cohesiveness deterioration of cement paste. As the percentages of POC increased in the production of UHPC, the failure of the UHPC specimens could be minimized. Overall, it can be concluded that the POC-UHPC specimens possessed higher toughness compared with plain UHPC specimens.

4.4 Summary

The study highlighted the effect of palm oil clinker (POC) as partial replacement of aggregate in producing UHPC. Overall, it has been observed that when the age of curing ages of UHPC specimens is prolonged, the both compressive strength of plain UHPC and POC-UHPC also would increase. However, the results proved that there is no better improvement in terms of strength properties when incorporating POC into UHPC mixes. The compressive strength was reduced significantly as the percentages of POC content increased. Despite of this drawbacks, there’s a positive effect in terms of toughness of POC-UHPC. Therefore, it can be demonstrated that the use of POC-UHPC is not suitable to be used when high strength is priority. However, POC-UHPC may be used in placed where toughness is more important than strength such as construction of road foundations and barriers.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This present study investigated the strength properties and mode of failure of four (4) series of plain ultra-high performance concrete (UHPC) and POC-UHPC. Plain UHPC was prepared as a control mix without the incorporation of POC. Based on the analysis of results, several conclusions can be drawn out.

i. The UHPC specimens developed higher compression strength between 200 ° C to 400 ° C. The UHPC specimens reduced in strength when exposured to temperature above 400 ° C. At 800 ° C, the strength are worsened.

ii. The maximum compressive strength for all specimens were recorded at 28 days. The percentage of palm oil clinker that were found suitable to add in UHPC mixture is in the range of 5 % to 10 %.

iii. The specimens cannot be classified as ultra-high performance concrete (UHPC) due to compression strength of the specimens lower than 150 N/mm^2. It is classified as high performance concrete (HPC).

iv. The plain concretes suffered brittle damage and were crushed up under either temperature. By contrast, the UHPC concrete incorporating palm oil clinker improved a lot in ductility and remained its integrity under the compressive loading.

5.2 Recommendation

There are some recommendations that can be employed in this present study if this study continues in more detail in future. The recommendations can be used to improve this study in the future are:

i. Compaction is one of the important process that should be more concerned to give results in good performance of concrete.

ii. Increase the number of specimens to get more accurate data of specimens.

iii. Explore the influences of cement type, aggregate shape and surface on the mechanical property of UHPC need to be taken into consideration for further research.

iv. Further investigations are needed to clarify for instance which are the characteristics that maximize the concrete performance and which treatments can maximize the rubberized concrete performance.

v. Finally, it is clear that further work is needed to characterize the palm oil clinker in terms of origin, size, shape, grading, density and amount and study the influence of each of these parameters on the properties of concrete.

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