FLEXURAL BEHAVIOR OF LIGHTWEIGHT REINFORCED CONCRETE BEAM CONTAINING PALM OIL CLINKER AS AGGREGATES

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DEDICATION

I dedicated this thesis to my beloved wife, father and mother for

their supports and encouragement.

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ABSTRACT

Lightweight concrete (LWC) is an innovative technique for construction purposes. Lightweight concrete can be categorized into three different types which are no-fine concrete, lightweight aggregate concrete and aerated concrete. In this study, an investigation on lightweight concrete was carried out using palm oil clinker (POC) as lightweight aggregates. Two mixes of lightweight concrete were developed, named as POCC100 and POCC50 where each mix utilized 100% and 50% replacement of fine and coarse aggregates. The POC concrete mixture was used in order to cast the structural reinforced concrete beam. The physical and mechanical properties of fine and coarse POC aggregates were investigated in term of sieve analysis, bulk density, specific gravity, fineness modulus and ACV test to confirm the suitability to replace normal fine and coarse aggregates. The fresh and hardened POC concrete was tested and compared to the normal concrete (NC). The hardened state of the concrete was investigated through density test, water absorption, ultrasonic pulse velocity, cube compressive, splitting tensile, flexural tensile, modulus of elasticity and Poisson's ratio. From density test, POC concrete can be considered as a lightweight concrete since the density of the POC concrete obtained was 1990 kg/m^3 which are below than usual normal weight concrete density. The concrete mechanical properties test results on POCC100 and POCC50 show that the concrete compressive strength was only 14.30% and 4% less than the NC, respectively. Flexural beam test were conducted on three different beam specimens, i.e. control beam (NC), POCC100 and POCC50 beams. The tested results of the POC reinforced concrete beam show that the ultimate load of the POCC100 and POCC50 beams was comparable to about 88% and 95% to NC beam, respectively. Finding in this study found out that replacement of POC showed lower value of compressive strength by 13% compared to NC. However, replacement of POC benefits in weight reduction by 15% compared to NC. As a conclusion, POC is considered suitable to replace fine and coarse aggregates in the concrete proportion. In terms of sustainability of solid waste management, the application of the POC in construction will reduce the redundant of by-products resulted from the palm oil industries.

ABSTRAK

Konkrit ringan merupakan teknik inovasi bagi tujuan kerja pembinaan. Konkrit ringan dapat dikategorikan kepada tiga jenis yang berbeza iaitu konkrit tanpa agregat halus, konkrit agregat ringan dan konkrit berudara. Dalam kajian ini, penyelidikan terhadap konkrit ringan menggunakan batu hangus kelapa sawit (POC) sebagai agregat ringan telah dijalankan. Dua campuran konkrit ringan dibangunkan dan dilabelkan sebagai POCC100 dan POCC50 mengikut kadar gantian agregat kasar dan halus sebanyak 100% dan 50%. Konkrit campuran POC kemudiannya digunakan untuk pembinaan stuktur rasuk konkrit bertetulang. Sifat-sifat fizikal dan mekanikal bagi batu hangus kelapa sawit halus dan kasar dikaji dari segi analisis ayakan, ketumpatan pukal, graviti tertentu, modulus kehalusan dan ujian ACV bagi memastikan tahap kesesuaian penggantian terhadap agregat halus dan kasar. Konkrit basah dan konkrit keras POC diuji dan perbandingan dibuat terhadap konkrit biasa (NC). Konkrit keras diuji melalui ujian ketumpatan, ujian kadar serapan, ujian halaju nadi ultrasonik, ujian mampatan kiub, ujian pecahan kekuatan tegangan, elastik modulus dan nisbah Poisson. Daripada ujian ketumpatan, konkrit POC dikategorikan sebagai konkrit ringan memandangkan ketumpatan yang diperolehi konkrit tersebut ialah 1990 kg/m^3 iaitu lebih rendah berbanding nilai ketumpatan konkrit biasa. Ujian mampatan terhadap konkrit keras POCC100 dan POCC50 menunjukkan keputusan 14.30% dan 4% kurang daripada NC. Ujikaji lenturan terhadap rasuk telah dijalankan ke atas tiga spesimen rasuk iaitu rasuk konkrit biasa (NC), rasuk POCC100 dan POCC50. Hasil dapatan menujukkan beban muktamad rasuk konkrit bertetulang POCC100 dan POCC50 adalah sebanyak 88% dan 95% berbanding NC. Hasil dapatan daripada kajian ini menunjukkan penggantian POC memberikan kadar mampatan 13% lebih rendah berbanding NC. Walaubagaimanapun, penggantian POC memberikan kelebihan dari segi pengurangan berat sebanyak 15% berbanding NC. Kesimpulannya POC dikenalpasti sebagai bahan gantian yang sesuai digunakan untuk menghasilkan konkrit. Dari segi kelestarian pengurusan sisa pepejal, penggantian POC dalam pembinaan akan mengurangkan lebihan produk sampingan yang terhasil melalui industri minyak sawit.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
CEB	-	Euro-International Committee for Concrete
LWAC	-	Lightweight aggregates concrete
POC	-	Palm Oil Clinker
LWA	-	Lightweight aggregates
BS	-	British Standard Institution
ASTM	-	American Society for Testing and Materials
NC	-	Normal concrete
POCC	-	Palm oil clinker concrete
POCC50	-	Palm Oil Clinker Concrete with 50% fine and coarse replacement
POCC100	-	Palm Oil Clinker Concrete with 100% fine and coarse replacement
AIV	-	Aggregate impact value
ACV	-	Aggregate crush value
DOE	-	Department of Environment's Design Method
UPV	-	Ultrasonic pulse velocity
OPC	-	Ordinary Portland Cement
OPS	-	Palm oil shell
POFA	-	Palm oil fuel ash
OPSC	-	Oil Palm Shell Concrete
CSA	-	Canadian Standard
FIP	-	Federation internationale de la precontrainte
PP	-	Particle packing
MOE	-	Modulus of elasticity
NWC	-	Normal weight concrete beam
LECA	-	Lightweight expanded clay aggregates
CC	-	Control concrete
CSAC	-	Coconut shell aggregates concrete
DSSF	-	Discontinuous structural synthetic fibre

PSCC	-	Palm oil clinker concrete
SSD	-	Saturated surface dry
OD	-	Oven-dried
LVDT	-	Linear Variable Displacement Transducer
SD	-	Standard Deviation
COV	-	Coefficient of Variation

LIST OF SYMBOLS

kg/m^3	-	Kilogram per meter cube
mm	-	Milimeter
%	-	Percentage
MPa	-	Mega Pascal
N/mm^2	-	Newton per millimeter square
V_f	-	Volume of fiber
ε_{st}	-	Ultimate strain of high steel bar is
ε_{cc}	-	Ultimate strain for concrete
F_{cc}	-	Force in concrete compression
F_{st}	-	Force in tensile steel
A_s	-	Assumption of the area of tensile steel to be used in the design
M	-	Moment Resistance
ε_{st}	-	Ultimate strain of high steel bar is
ε_{cc}	-	Ultimate strain for concrete
E	-	"Modulus of elasticity"
σ	-	Stress from the slope
ε_a	-	Longitudinal strain at stress
μ	-	"Poisson's ration"
f_{ct}	-	Splitting tensile strength
f_{cf}	-	Flexural strength
μm	-	Micrometer
kN	-	Kilo Newton
SO_3	-	Sulfate Oxide
Cl	-	Chloride
°C	-	Degree Celsius
km/s.	-	Kilometer per second
μs	-	Microsecond
A_c	-	Cross sectional area of specimen
mm^2	-	Milimeter square

m^3	-	Meter cube
GPa	-	GigaPascal
Δ_y	-	Deflection
$\mu\varepsilon_S$	-	Ultimate Steel Strain
$\mu\varepsilon_c$	-	Ultimate Steel Concrete
M_{exp}	-	Experimental ultimate moment
M_{theo}	-	Theoretical ultimate moment
fy	-	Steel yield Strength
fcu	-	Concrete Compressive Strength

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Reinforced concrete is an element that has been established for civil engineering purposes such as the construction of building, bridges, dams, railways or even highways for a long period of time. Reinforced concrete was invented in late 1800's by the French industrialist. Reinforced concrete is a combination of two composite materials, which are concrete and reinforcement steel bar embedded inside the concrete. Concrete and reinforcement steel bar have contradictory properties. Concrete has high compressive strength and low tensile strength, while reinforcement steel bar has high tensile strength but has low compression. By combining these two advantages, it is due to produce structural materials that are strong in both compression and tension.

Lightweight concrete is a concrete which by one means or another has been made lighter than conventional concrete. The most familiar product is made from sand and gravel or crushed rock and cement. It has been suggested that lightweight concrete can be defined as a concrete made from the lightweight aggregate. According to American Concrete Institute (ACI 318), the density of hardened concrete is between 1840 kg/m^3 to 2000 kg/m^3. Lightweight concrete is a concrete that is lighter than normal weight concrete which usually ranged between 2240 – 2400 kg/m^3. Euro-International Committee for Concrete (CEB, 1977) classified lightweight concrete as having densities between 1200 – 2000 kg/m^3.

There are many advantages obtained when the concrete density is low, such as reduction of dead load, faster building rates, lower haulage and handling costs. The weight of a building in terms of the loads transmitted by the foundations is an important factor in design, particularly in the case of high-rise buildings. In framed structures, a considerable saving in cost can be brought about by using lightweight concrete for the construction of the floors, partitions, and external cladding.

Basically, there is only one way to produce the lightweight concrete, which is by including air in the concrete composition. This, however, can be achieved by three different methods: First, by excluding the fine aggregates from aggregate grading. This method was named *as no-fines* concrete. The second method is known as lightweight aggregates concrete, by replacing the normal aggregates such as river sand and crushed granite with hollow and porous aggregates. The third method to produce the lightweight concrete is known as *aerated concrete* where the gas bubbles were created in the fresh concrete or other method using the foam materials to form a *foamed concrete* The best alternative way to create the lightweight concrete to achieve sustainable concrete is by using waste by-product as a replacement to the conventional material in the mix (Pelisser et al., 2011). Hence in this study, a structural lightweight reinforced concrete beam using Palm Oil Clinker (POC) as coarse and fine aggregates was constructed to understand the potential of the lightweight aggregates concrete when using POC aggregates to replace the conventional aggregates.

1.2 Problem Statement

Construction industry has becomes the most important sector in many countries, especially to a developing country like Malaysia. Every year Malaysia government allocated some amount of money for the construction industry to ensure the development of the country continues moving forward and advanced in term of technology. Higher demand in construction sector has caused developers to finish the projects within short period of time. Using an innovative materials such as the

application of lightweight concrete structures has turned out to be the answer to increase population and development.

Government has to step in to provide the solution for the locals by constructing affordable housing scheme that will not only offer a reasonable price but also promise in rapid construction time. Current construction using normal concrete always result in massive design structures. There is a need to reduce the dead load of the structures which automatically save the construction cost. Hence, the application of lightweight aggregates concrete is a crucial matter in order to advise a solution to reduce construction cost. Therefore, research on POC as one of the LWA material is important in order to study its application in structure buildings.

Source of fine and coarse aggregates has reached minimum level, yet the development demand keeps on increasing (Alengaram et al., 2013). Lacking natural sand and coarse aggregates as main materials to produce the concrete mixture could decrease the construction activities. By using of lightweight concrete the normal aggregates, natural sand and crushed granite are replaced with the porous aggregates which will include air in the mix and will make the concrete lighter.

Malaysia is one of the world's largest palm oil producer and manufacturer with 19.86 million tons of palm oil and exported 18.47 million tons annually (MPOB, 2019). This could cause the problem of deterioration of the environment since only 10% of fresh fruit and kernel were used in processing the palm oil, while another 90% remain in the form of waste (Dungani et al., 2018). Hence, it is suggested that a study be conducted on the possibility to reuse and recycle the POC to be utilized as coarse and fine aggregates to produce the lightweight aggregates concrete.

1.3 Objectives of the Study

The aim of this study is to investigate the possibility of using POC in concrete proportion to produce a lightweight concrete. There are three objectives listed in order to achieve the aim of this study,

i. To investigate the physical and mechanical material properties of Palm Oil Clinker (POC) as fully and partially replacement of coarse and fine aggregates.
ii. To investigate the fresh and hardened state properties of POC concrete as compared to NC.
iii. To investigate the structural behaviour of reinforced POC lightweight concrete beams under flexural test.
iv. To compare the experimental results of beam testing with current code of practices.

1.4 Scope of Study

All the testing methods used throughout this study complied with British Standard Institution (BS) and American Society for Testing and Materials (ASTM). In this study, POC was utilized as both coarse and fine aggregates for lightweight aggregates concrete beam samples. The size of coarse and fine aggregates used in this study was maximum 10mm and 4.75mm respectively. Three concrete mixes were developed in this study which is normal concrete (NC), POCC50 and POCC100 where the replacement of the fine and coarse aggregates is at 50% and 100% replacement respectively.

The physical properties of POC that were tested in this study including sieve analysis, specific gravity, moisture content, water absorption, loose bulk density and fineness modulus. For the mechanical properties of POC, two testing methods were performed which are aggregate impact value (AIV) and aggregate crush value (ACV). These test are to ensure that POC meets the requirement to be used as coarse

and fine lightweight aggregates to produce the lightweight aggregates concrete. A mix design of POC lightweight aggregates concrete and normal weight concrete (NC) were developed using ACI and DOE methods respectively.

The second phase deals with mechanical properties testing of concrete, POC lightweight aggregates concrete were compared to normal weight concrete. Several tests were conducted to obtain the hardened state of concrete mechanical properties, which are water absorption test, ultrasonic pulse velocity (UPV) test, density test, water absorption test, compressive strength, splitting tensile strength, flexural strength and elastic modulus (E-value) test. Slump test was carried out for fresh state concrete to measure the workability of the concrete. The structural behaviour of normal and lightweight aggregates under-reinforced concrete beams were tested under flexural to investigate the ultimate load, load-deflection behaviour, crack pattern, mode of failure and load-strain behaviour between NC, POCC50 and POCC100 beams.

1.5 Significance of Study

This research is expected to give a better understanding of the use of POC as a possibility to replace the fine and coarse aggregates in structural concrete. As explained, the POC lightweight reinforced concrete beams will benefit the future construction industry with faster building rates, reduction of dead load of the structure and technically the construction cost could also be reduced due to reusage of waste by-product materials as both coarse and fine aggregates to replace the conventional aggregates in concrete mix. Moreover, the utilization of POC will lead to a cleaner and sustainable environment.

1.6 Thesis Outline

In this thesis, the compilation of varies literature data related to lightweight concrete, lightweight aggregates, POC, POC concrete and design of reinforced concrete beams are presented in Chapter 2. Chapter 3 deal with the details of research method in this study. In Chapter 4, material properties of POC and properties of fresh and hardened concrete of POC are discussed in detailed. The discussion on structural behaviour of reinforced concrete beam of POC and normal concrete are the subjects of Chapter 5. Chapter 6 deals with the conclusion and recommendation for future research.

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