PERFORMANCE OF LIGHTWEIGHT CONCRETE USING PALM OIL CLINKER AGGREGATES FOR PRECAST APPLICATION

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To my beloved parents, siblings, wife and daughter

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ABSTRACT

Palm oil clinker (POC) is a waste from the incineration process of palm oil shell and palm oil fibre which can be easily obtained from palm oil mill. This study focused on the 100% replacement of fine and coarse POC aggregates in concrete. The utilization of POC has been accepted by researcher to produce lightweight concrete and has good potential to replace natural aggregates. In this study, the characterization of fine and coarse aggregates consist of the physical and mechanical properties. Specific gravity, water absorption, dry loose bulk density, moisture content, sieve analysis, fineness modulus and Los Angeles abrasion tests were conducted to evaluate the physical properties. While for the mechanical properties of aggregate, tests on aggregate crushing value and aggregate impact value were carried out. It was found that the coarse and fine POC aggregates produce a density of 817.17 kg/m^3 and 917.82 kg/m^3, respectively, which were lighter than normal granite and sand as much as 36.85% and 29.45%. This is due to the porous nature of POC aggregates. POC absorbs excessive water which contributes to higher water absorption of 15.17% and 5.35% for fine and coarse, respectively. The sieve analysis result shows that fine and coarse POC comply with American Society for Testing and Materials (ASTM) C330/330M (2014), thus indicates that fine and coarse POC aggregates can be considered as a well-graded aggregate. A concrete mixture consists of 100% fine and coarse POC aggregates were then designed according to American Concrete Institute (ACI) 211.2 (1998), producing lightweight concrete with a density of 1990.33 kg/m^3. The normal weight concrete (NC) and lightweight concrete or later known as palm oil clinker concrete (POCC) were tested for its fresh and hardened properties. Slump test was performed to assess its workability while for the hardened concrete tests, density, water absorption, ultrasonic pulse velocity, compressive strength, tensile splitting, flexural strength, modulus of elasticity and Poisson's ratio tests were conducted. To evaluate suitability in the structural precast application, normal concrete wall (NCW) and lightweight precast wall (LPW) panels were constructed and tested under static loading. LPW panel exhibited lower axial load capacity by 44.13% from NCW and this is mainly due to the lower initial stiffness. Moreover, the higher Poisson's ratio value for POCC reflects the higher lateral displacement recorded by LPW at peak load which was 4.46 mm compared to only 1.1 mm for NCW. The failure mode and cracking pattern for both panels were similar except LPW exhibited concrete spalling during failure. The utilization of POC aggregate shows significant impact as LPW had larger strain at lower load. From the study conducted, POCC with air voids in the concrete contributes to lower initial stiffness of LPW. In conclusion, the LPW is suitable to be used as low load structural members.

ABSTRAK

Batu hangus kelapa sawit (POC) ialah sisa buangan dari proses pembakaran kulit kelapa sawit dan serat kelapa sawit yang mudah didapati di kilang kelapa sawit. Kajian ini fokus kepada penggantian 100% aggregat POC halus dan kasar di dalam konkrit. Penggunaan POC dipersetujui oleh penyelidik dalam menghasilkan konkrit ringan selain mempunyai potensi bagi menggantikan aggregat semulajadi. Ciri-ciri POC yang dikaji di dalam kajian ini meliputi ciri-ciri fizikal dan mekanikal aggregat. Graviti tentu, serapan air, ketumpatan pukal longgar kering, kandungan kelembapan, analisis ayakan, modulus kehalusan dan ujian lelasan Los Angeles dilakukan untuk menilai ciri-ciri fizikal. Manakala bagi ciri-ciri mekanikal aggregat, ujian nilai kehancuran aggregat dan nilai impak aggregate dilakukan. POC kasar dan halus mempunyai nilai ketumpatan 817.17 kg/m^3 dan 917.82 kg/m^3, di mana nilai ini lebih rendah berbanding granit dan pasir sebanyak 36.85% dan 29.45%. Ini disebabkan oleh sifat POC yang berongga. Sifat menyerap air POC menyebabkan nilai serapan air tinggi iaitu sebanyak 15.17% untuk POC halus dan 5.35% untuk POC kasar. Analisis ayakan POC halus dan kasar mematuhi *American Society for Testing and Materials* (ASTM) C330/330M (2014) yang menandakan bahawa aggregat POC halus dan kasar dikelaskan sebagai aggregat bergred baik. Campuran konkrit mengandungi 100% aggregat halus dan kasar direka berpandukan *American Concrete Institute* (ACI) 211.2 (1998) bagi menghasilkan konkrit ringan dengan ketumpatan 1990.33 kg/m^3. Konkrit berat biasa (NC) dan juga konkrit ringan yang kemudiannya dikenali sebagai konkrit klinker kelapa sawit (POCC) diuji untuk sifat konkrit basah dan sifat konkrit keras. Ujian runtuhan dilakukan bagi menilai kebolehkerjaan manakala bagi konkrit keras, ujian ketumpatan, serapan air, halaju denyut ultrasonik, kekuatan mampatan, mampatan tegangan, kekuatan lenturan, modulus elastik dan nisbah Poisson turut dilakukan. Bagi menilai kesesuaian aplikasi di dalam struktur konkrit pratuang, dinding konkrit berat biasa (NCW) dan dinding ringan pratuang (LPW) dibina dan diuji dibawah tekanan statik. Panel LPW menunjukkan nilai keupayaan yang lebih rendah dari NCW sebanyak 44.13% yang disebabkan oleh nilai kekukuhan awal yang rendah. Nilai nisbah Poisson yang tinggi turut menyebabkan LPW mempunyai nilai sesaran yang tinggi iaitu 4.46 mm manakala NCW hanya 1.1 mm. Mod kegagalan bagi kedua-dua panel didapati adalah kehancuran konkrit tetapi LPW turut menunjukkan pecahan konkrit. Penggunaan aggregat POC menunjukkan hasil yang ketara di mana LPW mempunyai terikan yang lebih besar ketika beban yang rendah. Hasil kajian menunjukkan POCC dengan udara terkandung di dalam konkrit menyumbang kepada nilai kekukuhan awal yang rendah untuk LPW. Kesimpulannya, LPW didapati hanya sesuai untuk digunakan sebagai struktur untuk beban rendah.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ACV	-	Aggregate crushing value
AIV	-	Aggregate impact value
ASTM	-	American Society for Testing and Materials
BS	-	British Standards
CIDB	-	Construction Industry Development Board
COV	-	Coefficient of variation
DOE	-	Department of Environment
FCSP	-	Foamed concrete sandwich panel
IBS	-	Industrial building system
LPW	-	Lightweight precast wall
LVDT	-	Linear variable displacement transducer
LWA	-	Lightweight aggregate
LWAC	-	Lightweight aggregate concrete
LWC	-	Lightweight concrete
LWECC	-	Lightweight expanded clay concrete
LWPSC	-	Lightweight pumice stone concrete
M-sand	-	Manufactured sand
NC	-	Normal concrete
NCW	-	Normal concrete wall
OPC	-	Ordinary Portland cement
OPS	-	Oil palm shell
PFA	-	Pulverized fly ash
POC	-	Palm oil clinker
POCC	-	Palm oil clinker concrete

POS	-	Palm Oil Shell
PP	-	Particle packing
SCC	-	Self-compacting concrete
SCLWC	-	Self-compacting lightweight concrete
SD	-	Standard deviation
SP	-	Superplasticizer
UPV	-	Ultrasonic pulse velocity

LIST OF SYMBOLS

A	-	Mass of oven-dry specimen
A_c	-	The cross-sectional area of the specimen which was subjected to the compression load
A_{sc}	-	The area of steel reinforcement bar
$A_{s,max}$	-	Maximum area of reinforcement required
$A_{s,min}$	-	Minimum area of reinforcement required
B	-	Mass of saturated surface-dry sample in air
B_1	-	Mass of pycnometer filled with water to calibration mark
C	-	Apparent mass of saturated test sample in water
C_{nom}	-	Nominal cover
C_1	-	Mass of pycnometer filled with specimen and water to calibration mark
D	-	Mass of dried sample
d	-	Diameter of the specimen
d_1	-	Horizontal dimension of prism specimen
d_2	-	Vertical dimension of prism specimen
E	-	Modulus of elasticity
F	-	The maximum load at failure
f_c	-	Compressive strength
f_{cd}	-	The design compressive strength of concrete
f_{cf}	-	Flexural strength
f_{ct}	-	Tensile splitting strength
$f_{k, exp}$	-	Experiment compressive stress of wall
$f_{k, theo}$	-	Theoretical compressive stress of wall

f_y	-	The characteristic yield strength of concrete
G	-	Mass of the aggregate and the cylinder
H	-	Height of the wall
H/t	-	Slenderness ratio
h	-	Width of the wall
I	-	Distance between the supporting rollers
I_m	-	Moment of inertia
i	-	The radius of gyration about the axis considered
k	-	Factor for fully restrained wall against rotation
L	-	Length of specimen
l_e	-	Effective length
M_{Ed}	-	The design bending moment
M_{o2}	-	First order moment
M_1	-	Mass of test specimen
M_2	-	Mass of the material passing the 2.36 mm test sieve
m_3	-	Mass of the precipitate of barium sulphate
N_{Ed}	-	The design ultimate axial load in the wall
P_u	-	Ultimate load for stocky wall
S	-	Mass of saturated surface-dry specimen (used in gravimetric procedure for density and relative density)
T	-	Mass of cylinder
T_1	-	Time taken by the pulse to transverse the length
t	-	Thickness of the wall
V	-	Volume of cylinder
V_1	-	Volume of the specimen
V_2	-	Used volume of 0.01 mol/l silver nitrate solution
υ	-	Poisson's ratio
W	-	Mass of original sample
W_1	-	Mass of original test sample
W_2	-	Final mass of the test sample
W_3	-	1000 g / mass of the aggregate
ε_a	-	Longitudinal strain at stress σ_a
ε_b	-	Longitudinal strain at stress σ_b

ε_{ta}	-	Transverse strain at stress σ_a
ε_{tb}	-	Transverse strain at stress σ_b
λ	-	Slenderness ratio
λ_{lim}	-	Slenderness limit
σ_a	-	Upper loading stress of the gradient from graph of stress versus strain
σ_b	-	Lower loading stress of the gradient from graph of stress versus strain
$\varnothing$	-	Capacity reduction factor for compression members

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Construction industry contributes directly to the development of an area. With the increase of population, rapid development of public facilities such as road, infrastructure and residential buildings are essential. Thus, the demand for concrete which consists of four basic materials such as cement, sand, crushed granite and water has been increasing by time. Aggregate consumes about 60 % to 70 % of the total volume of concrete (Harmon, 2006). Dependency on these natural resources only had raise concerns toward the equilibrium of environment since the source will be depleted (Sharmin *et. al.*, 2015).

Whilst the construction of industrial building system (IBS) is focusing on utilizing precast panels in buildings, more studies were conducted to enhance the performance and production. Precast panel is a concrete panel that was cast in a factory earlier and then been transported to the site. It is being used as cladding since 1920s and has been widely used since 1950s (Rahim *et al.*, 2012).

The Malaysian government has urged the local construction industry to move on from conventional practice to precast products in all government projects since 1960s. Construction Industry Development Board (CIDB) was set up by the Malaysian government in 1994 in order to guide and to educate the local construction industry (Azman *et al.,* 2012). The precast panel is seen as a good alternative especially in improving quality and time reduction of construction project.

Meanwhile, Malaysia produced 19.96 million tonnes crude palm oil in 2015 with an increase of 1.5% from previous year (MPOB, 2015). The palm oil process produces 2.6 million tonnes of waste per year which has cause problem in finding the suitable disposable area (Basri *et al.,* 1999). Numbers of researches have been conducted to determine the suitable method of disposing the waste and the ability of this waste to be recycled. Among the materials that had been recognized suitable to be used in concrete production are palm oil clinker (POC) and palm oil shell (POS) (Ahmmad *et al*., 2014). POC can be used as a replacement for both coarse and fine aggregate. Furthermore, a study by Mohammed *et al.* (2013) reported that POC produced lighter density which fulfilled the requirement of lightweight aggregate (LWA) in lightweight concrete (LWC). The utilization of POC in LWC can help not only in waste disposing problem but also can reduce the dependency in the natural source.

POC is an aggregate with porous and solid character. It is a by-product of POS and oil palm fibre incineration used in generating electricity (Jumaat *et al.,* 2015). The light density makes it as a suitable material for LWC. Concrete with density 2000 kg/m^3 or less is considered under lightweight concrete according to BS EN 206 (2013). LWC has been used for a long time since the 18th century when Roman builds the pantheon. And it has widely been used in USA and Europe in the late 1990s to replace normal dense concrete. The used of POC can reduce the dead load and at the same time giving reduction to construction cost. In this study, lighter precast panels were produced using POC as fine and coarse aggregates. With a lighter precast panel, the cross section of structural members can be reduced and this will give some space to engineer to design a more sophisticated structure.

1.2 Problem Statement

Concrete is one of the most important materials in the construction industry. As the development keep on going, the demand for concrete will increase. The high demand of concrete requires a huge amount of sand and granite, leading to massive extraction of those materials. Tu *et al.* (2006) reported that 8 to 12 billion tones of natural aggregates been extracted annually. Depletion of natural sources to be used in concrete can cause ecological imbalance. Thus it is important to find an alternative material to replace both sand and granite.

Currently, the precast panel is facing difficulties in producing a lighter panel. More than that, the application of precast panels in the local building is still on a small scale. Precast panels need heavy crane during production and transportation. Lighter panels will eliminate the use of heavy machines, thus ease the assembling process at site. In this case, producing a lighter precast panel will help in eliminating those problems and most importantly, gain the interest from construction players. Several types of research have been carried out on lightweight precast panels, but with inclusion of waste material more research is seen required to make it more applicable (Cavaleri *et al.*, 2003; Carbonari *et al.*, 2012; Amran *et al.*, 2016). Lightweight panels reduce self-weight and thus lower the load carried by the foundation.

POC is a by-product from the incineration process of palm oil fiber and palm oil shell at palm oil mill. This waste is produced in a large quantity from all palm oil mill in Malaysia (Abutaha *et al.*, 2016). POC was normally dumped into the environment due to no significant application. This sparks concern among public, environmental activist and researchers. The reuse of POC in form of fine and coarse aggregates in concrete, so as to produce LWC is promising in reducing the amount of natural aggregates, apart from providing natural balance to the environment.

1.3 Aim and Objectives

The aim of this research is to produce a lightweight precast wall panel made of fine and coarse POC aggregates. The objectives of this research are as follows:

i. To evaluate the physical, mechanical and chemical properties of POC aggregates.
ii. To develop optimum mix design of lightweight concrete using 100 % replacement of fine and coarse POC aggregates and to investigate the fresh and hardened tests of palm oil clinker concrete (POCC).
iii. To investigate the structural behavior of lightweight precast wall (LPW) panel subjected to gravity load.
iv. To verify the experimental result with predicted values from previous researcher and codes.

1.4 Scopes of Study

This study was conducted through experimental works. All testing methods were in accordance to American Society for Testing and Materials (ASTM) and British Standards (BS). Both fine and coarse POC aggregates were used as 100 % replacement to produce a lightweight concrete with a designed strength of 30 N/mm^2 at 28 days. The size range for fine aggregate is from 150 µm to 4.75 mm and 4.75 mm to 9.5 mm for coarse aggregate.

The physical properties of fine and coarse POC aggregates were determined and compared with normal aggregate concrete (NC). This is because the POCC will significantly have lighter density and expected to have lower compressive strength. The physical properties being covered are specific gravity, water absorption, dry loose bulk density, moisture content, sieve analysis, fineness modulus and Los Angeles abrasion value. Meanwhile, the mechanical properties being covered are aggregate impact value and aggregate crushing value. In additional, chemical tests to determine sulphate and chloride content were also conducted. Fresh and hardened palm oil clinker concrete (POCC) properties such as slump test, density, water absorption test, ultrasonic pulse velocity test, compressive strength test, tensile splitting test, flexural splitting test and modulus of elasticity test were conducted to evaluate the performance of POCC as lightweight concrete.

LPW panel made of POCC was produced with a dimension of 1300 mm x 400 mm x 100 mm. The reinforced LPW wall was subjected to an axial load to study the cracking pattern, strength capacity, failure mode, load-displacement behavior and load-strain behavior.

1.5 Significance of Research

This research studied on the usage of POC as a replacement for fine and coarse aggregate in concrete. This replacement can help in the waste disposing problem of POC. Furthermore, it also can help to reduce the dependency on natural resources where the equilibrium of environment could be disturbed. The utilization of POCC in the lightweight precast panel has many advantages such as thermal insulation, high fire resistance, reduction in building weight, construction cost and period. The LPW with the utilization of waste material has high potential to be used in the construction of affordable houses where the amount of conventional aggregates can be reduced. Moreover, with the reuse of waste material the building constructed with LPW made of POCC can be categorized as a green building.

1.6 Thesis Outline

This thesis discusses in details about the material properties of POC aggregates and also the structural behaviour of LPW panel made of POCC. Chapter 1 covers the background of this study, problem statement, shows the aim and objectives, explain the scope of this study and the significance of this research. While Chapter 2 mainly discuss on the literature review on previous studies related to lightweight aggregate and wall. In Chapter 3, all testing that were used in this study were explained clearly. The results obtained from testing for material properties were presented and discussed in Chapter 4 while for the testing on wall was presented in Chapter 5. Finally, Chapter 6 summarize the conclusion of this study.

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