PERFORMANCE OF SELF-COMPACTING CONCRETE INCORPORATING PALM OIL FUEL ASH AND EGG SHELL POWDER AS PARTIAL CEMENT REPLACEMENT

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SPECIALLY DEDICATED TO MY BELOVED PARENTS:

KAMARUDDIN BIN JUSOH
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Thank you for your sacrifices, good deeds, generosity and giving hearts.

My love to all of you will remain forever.....

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With the name of Allah the Most Merciful and His messenger Prophet Muhammad p.b.u.h

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ABSTRACT

Self-compacting concrete (SCC), is an innovative concrete that uses less aggregates, but high content of cement compared to normal concrete. It is able to flow by itself and does not require compaction. Therefore, raw materials and natural resources are required in large quantities for SCC production. In order, to minimize the usage of the cement in the SCC, the use of agricultural wastes such as palm oil fuel ash (POFA) and eggshell powder (ESP) as partial cement replacement materials for an alternative preventive solution is suggested. This experimental work was conducted to study the potential combined utilization of POFA and ESP as partial cement replacement in SCC. The amount of POFA content ranged between 0% to 15% while ESP varied from 0% to 5% by weight of cement. A total of 90 cubes, 30 cylinders and 30 prisms were prepared for determining compressive, tensile and flexural strength of SCC repectively, while 30 cylinders were additionally prepared to determine modulus of elasticity and Poisson ratio. The physical, chemical, mechanical and microstructural properties were determined, in which it was observed that POFA had high silicon dioxide (62.1%) compared to ESP which had high percentage of calcium oxide (93.4%). Furthermore, based on the results, it was observed that the combined utilization of POFA and ESP enhanced the pozzolanic activity, thus, developing additional calcium silicate hydride (C-S-H) gels which are responsible for the gain in strength. The combined utilization of POFA and ESP as a cement replacement in SCC had good effect on the compressive and tensile strengths. It was found that 5% POFA and 2.5% ESP was an optimum mix to be used in SCC with 28 days of curing which had the compressive strength of 9.66% higher than the control sample achieved.

ABSTRAK

Konkrit padat sendiri (SCC), adalah inovatif konkrit yang mengandungi rendah kandungan agregat tetapi tinggi kandungan simen berbanding konkrit biasa. Ia dapat mengalir dengan sendirinya dan tidak memerlukan pemadatan. Oleh itu, bahan mentah dan sumber asli diperlukan dalam jumlah besar untuk penghasilan SCC. Bagi meminimumkan penggunaan simen dalam SCC, penggunaan bahan buangan pertanian seperti abu terbang kelapa sawit (POFA) dan serbuk kulit telur (ESP) sebagai bahan gantian simen sebagai alternative penyelesaian dicadangkan. Kajian ini menggunakan POFA dan ESP bersama-sama sebagai bahan pengganti simen dalam SCC. Kuantiti POFA digunakan antara 0% hingga 15%, manakala kuantiti ESP dari 0% hingga 5% berdasarkan berat simen. Sebanyak 90 kiub, 30 silinder dan 30 prisma disediakan untuk menentukan kekuatan mampatan, tegangan dan lenturan SCC, manakala 30 silinder juga disediakan untuk menentukan modulus keanjalan dan nisbah Poisson. Ciri-ciri fizikal, kimia, mekanikal dan mikrostruktural telah ditentukan, di mana didapati bahawa POFA mempunyai peratusan silikon dioksida yang tinggi (62.1%) berbanding dengan ESP yang mempunyai peratusan kalsium oksida yang tinggi (93.4%). Tambahan pula, berdasarkan pada keputusannya, ia didapati bahawa gabungan POFA dan ESP meningkatkan aktiviti pozzolanik, dengan itu pembentukan gel tambahan kalsium silikat hidrida (C-S-H) yang dapat meningkatkan kekuatan. Penggunaan POFA dan ESP sebagai pengganti simen dalam SCC mempunyai kesan yang baik ke atas kekuatan mampatan dan tegangan. Ia mendapati bahawa 5% POFA dan 2.5% ESP adalah campuran optimum digunakan dalam SCC dengan pengawetan 28 hari yang mempunyai kekuatan mampatan 9.66% lebih tinggi daripada sampel kawalan yang dicapai.

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LIST OF SYMBOLS & ABBREVIATIONS

%	-	Percentage
°C	-	Temperature
μm	-	Micrometre
Al_2O_3	-	Aluminium trioxide
ASTM	-	American Standard Test Method
BS	-	British Standard
C-S-H	-	Calcium-silicate-hydrate
$CaCO_3$	-	Calcium carbonate
CaO	-	Calcium oxide
$Ca(OH)_2$	-	Calcium hydroxide
cm^2/g	-	Centimeter square per grams
CO_2	-	Carbon dioxide
CRTs	-	Cathode ray tubes
ESP	-	Eggshell powder
FAMA	-	Federal Agricultural Marketing Authorities
Fe_2O_3	-	Ferric oxide
FKAAS	-	Faculty of Civil and Environmental Engineering
GDP	-	Gross domestic product
IBS	-	Industrialized building system
kg/m^3	-	Kilogram per cubic meter
kN	-	Kilonewton
$litres/m^3$	-	Litres per meter cubic
LOI	-	Loss of Ignition
MOE	-	Modulus of elasticity
MPa	-	Megapascal
MS	-	Malaysia standard
N/mm^2	-	Newton per millimeter square

OPC	-	Ordinary Portland Cement
POFA	-	Palm Oil Fuel Ash
PSD	-	Particle size distribution
SCC	-	Self-compacting concrete
SEM	-	Scanning electron microscope
SiO_2	-	Silicon oxide
SR	-	Sieve resistance
TiO_2	-	Titanium Oxide
UTHM	-	Universiti Tun Hussein Onn Malaysia
W/B	-	Water binder
W/C	-	Water content
XRF	-	X-ray fluorescence

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Malaysia is a successful developing country and forging ahead to become a developed nation. In order to be more successful, Malaysia has to improve its construction sector which has been playing a significant role in the accretion of its economy (Lee *et al.*, 2014). Considering the important role of the construction sector in the economic development of Malaysia, it is necessary for Malaysian government to give due attention and focus on the construction sector for qualifying the title of a developed nation.

Concrete materials are extensively used in the building and construction industries. Commonly, concrete is produced by using cement, sand, gravel and water. There are many different types of concrete being produced by using waste materials to reduce the utilization of cement, save the landfill areas and decrease the environmental pollution (Pourakbar *et al.*, 2015).

SCC also known as self-consolidating concrete is an innovative concrete technology which has a wide range of advantages compared to normal concrete. The advantages of SCC include faster construction, reduction in site workers, better and easy finishing, easy placement and reduction in noise level. SCC was developed to compensate for the shortage of skilled labour in the construction industry. Thus, it has been rendered efficient and beneficial from both technological and economic stand point. SCC has great advantages in being used in dense reinforcement, deep foundations and vertical structural members e.g column without any external efforts (Yakhlaf, 2013).

SCC contributes to industrialized building system (IBS) which is sustainable and environment friendly. With an ever-growing demand for affordable housing, conventional building construction being practiced in Malaysia is unable to fulfill the housing demand (Afif Iman *et al.*, 2018). Thus, adoption of innovative construction system such as IBS is much needed to overcome such raising demand.

SCC contains greater cement content as binder ranging from 430 kg/m^3 to 700 kg/m^3 (Alsubari *et al.*, 2015). In addition, using high cement content in the concrete mix is a disadvantage of this type of concrete from an environmental sustainability point of view.

Cement is an important ingredient for all kinds of concrete. The cement production generates carbon dioxide (CO_2) during the production of clinker thus causing global warming (Andrew, 2018). According to Ranjbar *et al.* (2014), about 0.7 to 1.1 ton of CO^2 per ton of the cement is produced and about 50% of this can be attributed to limestone calcination, 40% to fuel combustion in the kiln, and the remaining 10% to other manufacturing processes and product transportation. Ordinary Portland cement (OPC) is among the most popular construction material used. CO_2 emissions can be reduced by minimizing the use of OPC by using the cementitious materials such as fly ash (FA), POFA, ESP, silica fume (SF), and ground granulated blast furnace slag (GGBS) as partial replacements for cement to decrease cement consumption and hence its production.

The large quantities of industrial by-products are generated every year through the agricultural processing industries which have created environmental pollution as well as an economi burden on the industry regarding the disposal of such waste products (Alsubari *et al.*, 2015). Increasing environmental awareness, lack of space for land-fill and the ever-growing cost of disposal of waste products, has led to the utilization of waste materials. Utilization of waste products in construction materials such as concrete ultimately helps in reducing the amount of disposed landfill waste and CO_2 emission during the production of cement (Francis & Eldhose, 2017).

Malaysia is one of the world's largest palm oil producers and exporters. It generates 4 million tons of a waste product known as POFA annually, which is disposed of as solid waste (Mat Aris *et al.*, 2018). POFA is major waste that needs to be recycled.

Another waste material is Eggshells. It has been recorded that 2.8 million eggs are consumed daily especially chicken eggs (Ministry of Agriculture and Agro-Based Industry Malaysia, 2017). Due to its large consumption, the disposal of eggshell has the potential to cause significant environmental pollution. To overcome this, previous studies have utilized POFA and eggshells as a cement replacement individually (Alsubari *et al.*, 2015; Yong *et al.*, 2016; Sivakumar & Mahendran 2014; Yerramala 2014; Pliya, 2015).

POFA has pozzolanic materials and possesses a high content of silica oxide (SiO_2) but limited content of calcium oxide (Narendra & Pathrose, 2017) compared to ESP which has a high content of calcium oxide (CaO) and limited content of silica oxide (Yerramala, 2014). The SiO_2 of the treated POFA reacts chemically with the calcium hydroxide $Ca(OH)_2$ to form a secondary calcium-silicate-hydrate (C-S-H). This additional C–S–H is the main compound contributing to strength and it fills in the capillary pores to improve the microstructure of the cement matrix and the transition zone resulting in an enhancement of compressive strength (Le *et al.,* 2016).

It is hypothesized that if POFA and ESP are utilized together as a partial cement replacement, the extra CaO from the eggshell can act as a catalyst to POFA's pozzolanic reaction and ultimately increase the strength gain and increase the percent cement replacement.

1.2 Problem statement

SCC represents an innovation in the building industry due to its workability. SCC is able to flow under its own weight, filling perfectly the formwork even in the presence of congested reinforcement without vibration. The benefits of SCC include higher powder content, limited volume and nominal maximum size of coarse aggregate, superplasticizers presented in the design requirements to achieve self-compatibility (Bradu *et al.*, 2016). The higher powder content leads to the idea of replacement of cement with waste materials. At the same time, a considerable quantity of agricultural waste and disposal of other types of solid materials are posing serious environmental issues. To minimize the negative impact of the concrete industry through the explosive usage of raw materials, the use of agricultural wastes as supplementary cementitious materials, the source of which are both reliable and suitable for alternative preventive solutions promotes the environmental sustainability of the industry.

In Malaysia, the egg consumption was recorded at 2.8 million eggs daily especially chicken eggs (Astro Awani, 2016). The disposal of the eggshell has the potential to cause environmental pollution, due to its availability and chemical composition, hence proper management and treatment are required (Raji & Samuel, 2015). Nowadays, chicken eggshell had been listed worldwide as one of the worst environmental problems, causing undesirable odors, which cause irritation and affect the well-being of humans (State, 2012). In this case, it is noticeable that the waste produced by eggshells alone is extremely tremendous. So, by following this trend, the amount of eggshell waste produced was estimated to be same and will increase every year.

POFA is another major waste that needs recycling in Malaysia. Recently, Malaysia is said to be one of the largest producers of palm oil waste every year (Kushairi, 2019). POFA is the ash that is produced by burning the palm oil shell and husk as fuel in a palm oil mill boiler in order to produce steam to generate electricity for the palm oil extraction process. This material is usually sent to landfill without any commercial gain. To counter that several researchers had attempted to reuse POFA sustainably, and it was found that POFA has pozzolanic properties due to which it can be used as an alternative of cement in the construction industry. Specifically, as a unique cement replacement in materials of building construction.

Throughout the years, attempts have been made to use waste materials in the concrete to improve its mechanical properties as well as to reduce the issues related to waste disposal (Al-Hadithi *et al.*, 2016; Hama, 2017; Patnaik *et al.*, 2018). Major waste materials such as POFA, silica fume, quartz sand, ESP and others have been utilized in the concrete (Mohamad *et al.*, 2018; Mujah, 2016; Lu *et al.*, 2015). Several researchers were using a wide array of supplementary cementitious materials and waste products with concrete. This innovative utilization of waste materials aims at reducing the amount of cement in concrete along with finding an alternative disposal method for these waste materials.

Many researchers have studied the use of POFA and eggshell individually in normal concrete, high strength concrete and lightweight concrete (Munir *et al.*, 2015; Wan Yusof *et al.*, 2015). Previous studies reveal that agricultural wastes containing a high amount of silica could be used as a pozzolanic material. Sooraj (2013), stated that, in comparison between OPC concrete and concrete containing POFA, waste materials showed improvement in the mechanical properties of concrete. Another agricultural waste is eggshell. The studies on ESP as a cement replacement revealed that ESP can replace cement at an optimum percentage (Yerramala, 2014). It is a poultry waste with a chemical composition nearly same as that of the cement. Use of eggshell waste instead of natural lime to replace cement in concrete can have benefits like minimizing use of cement, conserving natural lime and utilizing a waste material.

The POFA has high content of silica oxide (Lim *et al.*, 2015) but less proportion of calcium oxide (Najim *et al.*, 2016) compared to ESP which has a high content of calcium oxide and less content of silica oxide. Therefore, the combination of supplementary materials of POFA and ESP provides a good composition suitable for being used as a cement replacement.

Based on POFA and ESP properties, the solid waste materials can either be used as supplementary cementitious materials or as replacement of fine aggregate in SCC. Therefore, recycling POFA and eggshells into the useful product gives a good potential for the agricultural industry, food manufacturing and much wider construction industry. It is because the usage of waste products can reduce the usage of cement in manufacturing, but can also reduce the cost of landfill activity and pollution. At the same time, it contributes to a significant improvement in the quality of concrete structures and opens up new fields for the application of SCC.

1.3 Objectives

The objectives of this research are:

i. To investigate the physical and chemical properties of POFA and ESP.
ii. To determine the fresh and mechanical properties of SCC incorporating POFA and ESP as partial cement replacement.

iii. To define the optimum percentage of POFA and ESP as partial cement replacement in SCC.

1.4 Scope of the study

This study focused on the physical and chemical properties of the material, workability of fresh SCC, microstructural analysis and hardened properties of SCC by using different percentages of ESP namely 0%, 2.5% and 5% and of POFA namely 5%, 10% and 15% as partial cement replacement. The limitation percentage of the materials are used based on the optimum percentage from previous study (Oyejobi *et al.*, 2018; Golizadeh & Banihashemi, 2015; Hama, 2017; Gowsika *et al.*, 2014).

The physical properties such as specific gravity, water absorption and particle size distribution of raw materials were analyzed. The chemical composition of POFA and ESP were investigated by x-ray fluorescence (XRF) test. The workability of fresh state SCC was determined by slump flow test, J-ring test and segregation test. Scanning electron microscope (SEM) used to investigate the morphology of POFA, ESP and the concrete for microstructural analysis. The mechanical properties such as compressive strength, splitting tensile strength, modulus of elasticity, Poisson's ratio and flexural strength of SCC were analyzed by utilizing different proportions of POFA and ESP.

Material preparation and casting were conducted according to requirements of the American Society for Testing and Materials (ASTM). To determine the effect of POFA and ESP, utilized as partial cement replacement, on the compressive strength of SCC three cubes were cast for each of the 7, 28 and 90 days curing regimes. Six cylindrical samples were cast for each mix proportion, three for split tensile tests and three for the compressive test to determine the modulus of elasticity and the Poisson's ratio on 28th day. Besides, the prisms having dimensions 100 mm x 100 mm x 500 mm were cast to examine the flexural strength and failure mode with 4-point load test for 28 days curing.

1.5 Significance of the study

The higher consumption of cement in SCC production, led to finding alternatives that can be used as partial cement replacement especially disposable and less valuable wastes from industry and agriculture, whose potential benefits can be realized through recycling, reuse and renewal. It is because the demand for concrete is increasing day by-day which needs to be resolved using supplementary cementing materials.

Therefore, the significance of this study is to gain knowledge and improve the strength of the SCC incorporating POFA and ESP as cement replacement. The importance of this study is to explore sustainable products made from the waste materials which can contribute to the reduction of agricultural waste residual.

In addition, this study can help in providing an idea and vision to other researchers or engineers regarding the potential applications of sustainable SCC. This research output will also contribute towards sustainability of available material resources and environmental protection through minimizing the usage of natural materials.

1.6 Thesis layout

This thesis covers the experimental study conducted in five chapters. Chapter one provides a brief background related to this study and the problems faced therein. The chapter also presents objectives, scope and significance of the study and the layout of report.

Chapter two discusses SCC and its advantages over normal weight concrete, utilization of supplementary cementitious materials which include POFA and ESP, and the innovative idea of SCC containing POFA and ESP rising from the environmental issues caused by the production of cement.

Chapter three presents the research framework associated with this experimental work involved in this study. It contains the materials used and their preparation, detailed mix proportions, mixing procedures, curing as well as various tests related to this study are discussed.

Chapter four presents the results obtained and their analysis to provide a discussion of the results. The physical and chemical properties of POFA and ESP are discussed. While the effect of partial cement replacement by utilizing POFA and ESP on the fresh and hardened state properties of SCC is also discussed. The optimum mix proportions of POFA and ESP in SCC are also discussed.

Chapter five concludes based on the results obtained and provides recommendations for further research related to the development of SCC incorporating POFA and ESP.

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