SELF CONSOLIDATING HIGH PERFORMANCE PALM OIL FUEL ASH AND PULVERISED BURNT CLAY BLENDED CONCRETE

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To My Lovely Parents
Hassan Ogiri Attah and Rabi Hassan Ogiri

And
My Wives and Children

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ABSTRACT

Self-consolidating high performance concrete (SCHPC) is an advanced class of concrete that can flow through congested reinforcement or intricate geometric configurations under its own weight without any compaction activity and it does not segregate. Research and development in the use of supplementary cementing materials (SCM) to produce SCHPC have continued to gain attention worldwide. This is as a result of the global quest to reduce carbon dioxide emission to the threshold that will be tolerated by the earth. Despite the successes achieved by replacing cement with supplementary cementing materials (SCM), a number of drawbacks were unavoidable. The inclusion of palm oil fuel ash (POFA) into the SCHPC mixes increases the water demand due to high surface area and also induces segregation at replacement levels above 20%. In contrast, the inclusion of pulverised burnt clay PBC in the mix reduces the water demand due to lower surface area and improves the rheological properties of SCHPC at a replacement level of up 37.5%. Although PBC improves the rheological properties of SCHPC, its contribution to strength development is less effective in comparison to POFA. This research, therefore, focuses on the impact of blended POFA and PBC on the fresh and hardened properties of SCHPC. Assessment of the microstructure, physical and chemical characteristics of the binders was carried out. Furthermore, a simple mix design approach and the evaluation of the fresh and hardened properties of the SCHPC systems were executed. Various techniques, including the use of X-ray diffraction, scanning electronic microscope, Particle size analysis, BET surface area analysis and thermogravimetric analysis were used to study the microstructure of the SCM and the hardened SCHPC systems. Series of paste, mortar and concrete were prepared with blended POFA and PBC at a replacement level of 10%, 15%, 20% and 30%, using water to binder ratio (W/B) of 0.30, 0.35 and 0.40 respectively. Fresh properties of the paste, mortar and concrete were studied with respect to their filling ability, passing ability, segregation resistance, unit weight, air content and heat of hydration. The hardened properties examined are; mechanical strengths, deformation characteristics and durability properties. A 4-phased investigation revealed that both POFA and PBC are good pozzolanic materials having excellent physical and chemical properties. At 30% replacement, the filling ability was improved by 7%, the passing ability was improved by 7% and the segregation index was reduced from 7 to 2.4%, with a visual stability index of 0. The unit weight and air content decreased by 2.5% and 5.6%, respectively, while the heat of hydration was reduced by 19%. Also, the mechanical strengths were increased between 5 to 6% and the increase in the drying shrinkage values was less than 0.01%, while the modulus of elasticity was increased by 4%. The durability and microstructural characteristics of the respective SCHPC were significantly improved. Consequently, a blend of POFA and PBC of up to 30% (15% POFA and 15% PBC) with a high range water reducer dosage of $\leq$ 2.5% was considered suitable for the production of SCHPC with W/B $\leq$ 0.3 and up 0.40.

ABSTRAK

Konkrit prestasi tinggi termampat sendiri (SCHPC) adalah konkrit kelas lanjutan yang boleh mengalir melalui tetulang yang sesak atau konfigurasi geometri yang rumit dengan beratnya sendiri tanpa sebarang proses pemadatan atau pengasingan. Penyelidikan dan pembangunan dalam penggunaan bahan tambah simen (SCM) untuk menghasilkan SCHPC telah mendapat perhatian di seluruh dunia. Ini adalah hasil daripada usaha global untuk mengurangkan pengeluaran karbon dioksida ke satu kadar yang boleh diterima oleh bumi. Berdasarkan kepada keperluan ini, penyelidikan ke atas penggunaan bahan simen alternatif mula menjadi keutamaan. Walaupun kejayaan dicapai dengan menggantikan simen dengan bahan tambah simen (SCM), beberapa kelemahan tidak dapat dielakkan. Penambahan POFA ke dalam campuran SCHPC meningkatkan penggunaan air disebabkan oleh luas permukaan nya yang tinggi dan juga mendorong pengasingan pada tahap penggantian melebihi 20%. Sebaliknya, dengan penambahan PBC dalam campuran boleh mengurangkan penggunaan air disebabkan oleh luas permukaan nya yang lebih rendah dan meningkatkan sifat-sifat reologi SCHPC ke peratus pengganti sehingga 37.5%. Walaupun PBC memperbaiki sifat-sifat reologi SCHPC, sumbangannya kepada pembangunan kekuatan adalah kurang berkesan berbanding dengan POFA. Kajian ini memberi tumpuan kepada kesan campuran POFA dan PBC ke atas SCHPC semasa basah (baru) dan keras. Penilaian mikrostruktur, fizikal dan kimia ciri-ciri pengikat telah dilakukan. Tambahan pula, pendekatan reka bentuk campuran mudah dan penilaian konkrit segar dan keras terhadap sistem SCHPC telah dilaksanakan. Pelbagai teknik, termasuk penggunaan pembelauan X-ray, imbasan mikroskop elektronik, analisis saiz zarah, analisis luas permukaan BET dan analisis termogravimetri telah digunakan untuk mengkaji mikro struktur SCM dan sistem SCHPC keras. Beberapa siri pes, mortar dan konkrit disediakan dengan campuran POFA dan PBC pada tahap penggantian 10%, 15%, 20% dan 30%, menggunakan air untuk nisbah pengikat (W / B) 0.30, 0.35 dan 0.40 masing-masing. Ciri-ciri semasa basah (baru) daripada pes, mortar dan konkrit telah dikaji berkenaan dengan kebolehan mengisi ruang, kebolehan untuk melepasi ringtangan terhadap, rintangan pengasingan, unit berat, kandungan udara dan haba penghidratan. Sifat-sifat keras yang dikaji ialah; kekuatan mekanikal, ciri-ciri ubah bentuk, ketahanlasakan. 4-fasa penyiasatan mendedahkan yang kedua-dua POFA dan PBC adalah bahan pozzolanik yang mempunyai ciri-ciri fizikal dan kimia yang sangat baik. Pada pengantian 30%, kebolehan mengisi ruang meningkat sebanyak 7%, kebolehan untuk melepasi ringtangan terhadap meningkat sebanyak 7% dan indeks pengasingan berkurang sebanyak 19%. Kekuatan mekanikal juga telah meningkat antara 5 ke 6% dan peningkatan nilai pengeringan dan pengecutan adalah kurang daripada 0.01%, manakala modulus keanjalan telah meningkat sebanyak 4%. Ciri-ciri ketahanlasakan dan mikrostruktur bagi SCHPC masing-masing juga didapati meningkat. Oleh itu, campuran POFA dan PBC sebanyak 30% (15% POFA and 15% PBC) dengan canapura bahan tambah pangurang air aras tingi dos kepekatan $\leq$ 2.5% telah didapati sesuai untuk penghasilan SCHPC dengan W/B $\leq$ 0.3 dan 0.40.

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LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Standard for Testing of Materials
BET	-	Brunauer Emmet and Teller
BI	-	Blocking Index
BS	-	British Standard
CSF	-	Column Segregation Factor
DTA -	-	Differential Thermal Analysis
EDX	-	Energy Dispersive X-ray
ER	-	Electrical Resistivity
FESEM	-	Field Emission Scanning Electron Micrograph
GGBFS-	-	Ground Granulated Blast Furnace Slag
HRWR	-	High Range Water Reducer
IS -	-	Indian Standard
ISCF	-	Inverted Slump Cone Flow
JF	-	J-Ring Flow
LOI	-	Loss on Ignition
MK -	-	Metakaolin
MOE -	-	Modulus of Elasticity
NVC -	-	Normal Vibrated Concrete
OFS	-	Orimet Flow Spread
OPC -	-	Ordinary Portland Cement
OPF	-	Optimum Packing Factor
OPV	-	Optimum Paste Volume
PBC -	-	Pulverised Burnt Clay
PF	-	Packing Factor
PFA -	-	Pulverised Fuel Ash

POFA - - Palm Oil Fuel Ash
PR - Passing Ratio
PSD - Particle Size Analysis
RCP - Rapid Chloride-ion Penetration
RHA - - Rice Husk Ash
RILEM - International Union of Testing and Research Laboratory for Materials and Structures
SCC - - Self-Compacting Concrete/Self-Consolidating Concrete
SCHPC - Self-Consolidating High Performance Concrete
SCM - - Supplementary Cementing Materials
SEM - Scanning Electron Micrograph
SF - - Silica Fume
SI - Segregation Index
SSD - Saturated Surface Dry
TGA - - Thermogravimetry Analysis
UPV - - Ultrasonic Pulse Velocity
UTM - - Universiti Teknologi Malaysia
VA - - Volcanic Ash
XRD - - X-ray Diffraction
XRF - X-ray Fluorescence

LIST OF SYMBOLS

A - Blended aggregate

A_c - Design air content (%)

A_{ca} - Absorption of coarse aggregate (%)

A_{fa} - Absorption of fine aggregate (%)

Al - Alumina

A_{sb}^{c} - Surface area of binder (m^2/m^3)

B - Binder

BD_{mad} - Maximum bulk density of air-dry aggregate blend (kg/m^3)

B_J Blocking step

C - Carbon

C_2S - Dicalcium silicate

C_3Al - Tricalcium aluminate

C_3S - Tricalcium silicate

Ca - Calcium

Ca - Calcium

$Ca(OH)_2$ Calcium hydroxide

CaO - Calcium oxide

C-A-S-H Calcium alumina silicate hydrate

Cl - Chloride

CO_2 - Carbon dioxide

C-S-H - Calcium silicate hydrate

D_h - Dosage of HRWR (% of binder by weight)

E_s - Modulus of Elasticity

Fe - Ion

f_{sp} - Splitting Tensile Strength

f_r - Flexural Strength

f'_c - Compressive Strength
H_2SO_4 Sulphuric acid
HRWR- High range water reducer (kg)
K - Potassium
M_{ca} - Moisture content of coarse aggregate (%)
M_{fa} - Moisture content of fine aggregate (%)
Mg - Magnesium
$MgSO_4$ Magnesium sulphate
P_{pbc} - PBC content (% of the binder by weight)
P_{pofa} - POFA content (% of binder by weight)
P_m - Permeability
P_r - Porosity
S Sand
S/B - Sand to binder ratio
SCM - Supplementary cementing materials
S^{da} - Saturation dosage of HRWR
SG_c - Specific gravity of cement
SG_{ca} - Specific gravity of coarse aggregate on saturated surface dry basis
SG_{caad} - Air-dry basis specific gravity of coarse aggregate
SG_{fa} - Specific gravity of fine aggregate on saturated surface dry basis
SG_{faad} - Air-dry basis specific gravity of fine aggregate
SG_{pbc} - Specific gravity of PBC
SG_{pofa} - Specific gravity of POFA
S_h - Solid content of HRWR (% by weight)
T_{500} - 500 mm slump flow time
T_{ISCF} - Inverted slump cone flow time
T_O - Orimet flow time
T_V - V-funnel flow time
U^{db} - Used dosage of HRWR
V_b^b - Volume fraction of binder (m^3/m^3)
V_{ca} - Absolute volume of coarse aggregate (m^3)
V_{caad} - Voids in air-dry basis compacted aggregate blend (%)
Vep - Excess paste volume (m^3/m^3)
V_{fa} - Absolute volume of fine aggregate (m^3)

V_{mp} - Minimum paste volume (m^3/m^3)
V_p - Paste volume (m^3/m^3)
V_p^a - Volume fraction of paste (m^3/m^3)
V_{ta} - Absolute volume of total aggregates (m^3)
W/B - Water to binder ratio (by weight)
W_b - Weight of binder (Cement plus POFA plus PBC) (kg/m^3)
W_b - Weight of binder (Cement plus POFA plus PBC) (kg/m^3)
W_c - Weight of cement (kg/m^3)
W_{ca} - Weight of coarse aggregate on saturated surface dry basis (kg/m^3)
W_{ca} - Weight of coarse aggregate on saturated surface-dry condition (%)
W_{caad} - Adjusted weight of coarse aggregate on air-dry condition (kg/m^3)
W_D - Water demand of SCM
W_{fa} - Weight of fine aggregate on saturated surface dry basis (kg/m^3)
W_{fa} - Weight of fine aggregate on saturated surface-dry condition (%)
W_{faad} - Adjusted weight of fine aggregate on air-dry condition (kg/m^3)
W_{HRWR} - Water content for the saturation flow time in the presence of without SCM
W_O - Water content needed for the same flow time without any HRWR (kg)
W_{OPC} - Percentage increase in water content required for the binder paste
W_{pbc} - Weight of PBC (kg/m^3)
W_{pofa} - Weight of POFA (kg/m^3)
W_R - Water reduction capacity of HRWR (%)
W_{SCM} - Percentage increase in water content required for the binder paste with
W_{ta} - Weight of total aggregate on the air dry basis (kg/m^3)
W_w - Weight of mixing water (%)
W_w - Weight of water (kg/m^3)
W_{wad} - Adjusted weight of mixing water (kg/m^3)
ρ_w - Density of water (kg/m^3)

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CHAPTER 1

INTRODUCTION

1.1 General Appraisal

The implementation of the Kyoto protocol in February 2005 mandated 35 countries to reduce their gas emissions between 2008 and 2012. The sole aim is to achieve the fixed quantitative objectives for the reduction or limiting of the six gases that are related to the greenhouse effect. Among the major challenges facing the cement manufacturing industry is the reduction of CO_2 emission into the atmosphere during the manufacture of Portland cement. Nonetheless, the use of supplementary cementitious materials has been advocated to be a viable solution (Hussin & Awal, 1997; Domone, 2006; Frı´as, *et al*., 2008). Within these few years, the use of both natural and artificial pozzolans such as volcanic ash (VA), pulverised fuel ash (PFA), ground granulated blast furnace slag (GGBFS), Metakaolin (MK), calcined clay, silica fume (SF), pulverised burnt clay (PBC), palm oil fuel ash (POFA), rice husk ash (RHA) and a host of others have been investigated. The materials are predominantly used in the form of industrial by-products and waste materials. Furthermore, their use as construction materials has indeed gained an appreciable level of acceptance as their use offers beneficial effects from both environmental and thermal points of view (Mehta, 1998; Frı´as, *et al*., 2008; Sukumar, *et al*., 2008; Meyer, 2009; Barbhuiya, 2011; Safiuddin, *et al*, 2011a;)

A major challenge facing the construction industry is to execute projects in harmony with the environment by adopting the concept of sustainable development. This involves the use of high performance and environmentally friendly materials produced at reasonable cost. Since concrete is the predominant building material, it is necessary to identify cheaper cement substitutes. Current researches on many supplementary cementing materials (SCM) such as fly ash, blast furnace slag, silica fume, metakaolin, rice husk ash, POFA, PBC and a host of others have revealed that the inclusion of such materials in concrete has the potential of improving both the fresh and hardened properties of concrete as well as curtail the rise in construction costs (Dinakar, *et al*., 2008; Hussin & Abdullah, 2009; Meyer, 2009).

Aside from the concerted efforts by the key players in the construction industry to successfully replace in part or in whole, the conventional Portland cement with green or eco-friendly cementitious materials, the challenges of ensuring that the so called green or eco-friendly concrete performs up to the required expectation has been the focus of many researches. Dated back to early 1980's the problem of durability of concrete structures was a major topic of interest and concern in countries like Australia, Britain, Canada, Germany, Japan, Sweden, USA, and a host of others. This concern stemmed out from the gradual decline in the number of skilled workers, which consequently led to the reduction in the quality of construction work. Consequently, the employment of self-compacting concrete (SCC) was proposed by Okamura in 1986 as the solution to this problem, as reported by Okamura & Ouchi (2003). Since then, a series of studies have been undertaken to address the fundamental issues that concerns the rheology, workability, mechanical and durability characteristics of the concrete (Schwartzentruber, *et al*., 2006; Nunes, *et al*., 2011; Heikal, *et al*., 2013).

Palm oil fuel ash (POFA) is generally classified as an agro-industrial waste. It is obtained from the processing of agricultural produce, where the waste generated undergoes further processing to generate electricity. In Malaysia alone, about 3 million tons of ash are generated annually. This quantity of ash is usually dumped on open fields, thereby constituting environmental pollution and health hazard (Sumadi & Hussin, 1995; Ismail, *et al*., 2010). A series of research have shown numerous benefits derivable by partially replacing cement with POFA for the production of normal, aerated, high strength and high performance concrete. These researches indicated that POFA can be used to replace cement up to 60% and reasonable strength values were obtained, ranging from 18N/mm^2 to 60.9N/mm^2 at 28 day hydration period (Hussin & Awal, 1997; Sata, *et al*, 2004; Chindaprasirt, *et al.*, 2007; Hussin & Abdullah, 2009; Tangchirapat, *et al.*, 2009; Abdul Awal & Hussin, 2011; Ismail, *et al.*, 2011; Safiuddin, *et al*, 2012b;) On the contrary, application of POFA in self-consolidating concrete (SCC) has not been extensively investigated.

Brick has remained the second most dominant material in the construction of residential houses, accounting for about 25% of the total building materials requirement by mass (RMIT, 2006; Page, 2007). Bricks are largely classified as waste when broken or damaged from the brick production line or from construction and demolition sites. This brick waste, together with concrete waste usually constitute up to 75% of construction and demolition waste that are, in most cases, dumped in open landfills (Crowther, 2000; Formoso, *et al.*, 2002; Demir & Orhan, 2003; Kharrufa, 2007). Although Indian standard (IS:1344-1981, 2008) has established the chemical composition and guidelines for the use of clay suitable for use as calcined clay pozzolans, its application in SCC and high performance concrete (HPC) has been less spectacular. Nonetheless, various researches carried out to investigate the potentials of using clay in the form of montmorilonite, kaolinite and illite as supplementary cementitious materials have revealed that partial replacement of up to 20% is beneficial both for the production of mortar and concrete (Malhotra & Dave, 1999; Sabir, *et al.*, 2001; Gonçalves, *et al.*, 2009; Kadri, *et al.*, 2011; Tironi, *et al.*, 2012).

1.2 Background of the Problem

Placement of concrete in forms and its durability requires adequate compaction to be executed by skilled labour. This compaction is necessary so as to eliminate entrapped air in fresh concrete in order to obtain a homogeneous mix with no cavities or honeycomb (Neville, 2000). Most of the time, Normal vibrated concrete (NVC) has a problem of compaction and tends to exhibit certain disadvantages such as; voids, cavities and microstructural cracks, which facilitates concrete deterioration as a result of ingress of deleterious agents such as Chlorides, acids and sulphates (Hearn, *et al*., 1994). This deterioration is possible due to the presence of transporting agent, usually in the form of liquid or gas (Dhir & Newlands, 1992). It has been acknowledged that the use of SCHPC has the potentials to solve most of these inherent shortcomings of NVC (Okamura, 1997).

One of the basic solutions towards achieving improved concrete characteristics both in the fresh and hardened state is the employment of self-consolidating concrete (SCC) or self-consolidating high performance concrete (SCHPC). Because it tends to transform the concreting operation by completely eliminating the need for vibration and allows the concrete to be consolidated through sections with congested reinforcement under its self-weight without any segregation (Demie, *et al*., 2011; Okamura & Ouchi, 2003).

“Concrete construction practice has always preferred fresh mixes because of ease of handling and placement”. Even with the enactment of ‘good practice’ guidelines which stresses the need for a thorough and effective compaction of traditional mixes, a majority of all the concrete produced were never adequately compacted. These may sometimes manifest on exposed surfaces or remain hidden and manifest through poor performance or total collapse of the structure (De Schutter, *et al*., 2008). Therefore, there is a need to replace NVC with SCHPC in areas where durability is a primary consideration.

Self-consolidating high performance concrete (SCHPC) is an advanced class of concrete that can flow through congested reinforcement or intricate geometric configurations under its own weight without any means of compaction and does not segregate (Okamura, 1997; Koehler & Fowler, 2007). These characteristics are achieved by increasing the powder content which seemingly is the disadvantage of SCHPC. Generally, SCHPC requires a larger quantity of powder content in comparison to the normal vibrated concrete (NVC) to produce a homogeneous and cohesive mix (Topçu & Uygunoglu, 2010).

Schlagbaum (2002) reported that the material cost of SCHPC is 38% and 23% higher than the cost of NVC in residential and structural applications respectively. Furthermore, it was reported that the cost of producing SCC with fly ash varies between 10 – 17% higher than that of ordinary concrete, depending on the quantity of fly ash used (Martin, 2002). Also, Ambrose & Pe´ra (2002) reported that the cost difference is around 15%. Nonetheless, recent research has discovered that by eliminating the cost of vibration work, reduction of labour, reduction in construction time and the use of inexpensive waste materials in SCHPC can reduce the overall cost of concrete work by 24.8% in comparison with NVC (Chung-Fah, *et al.*, 2011). [;

A research was carried out by Nehdi, *et al.* (2003) to optimize cost-effective high volume replacement to produce SCHPC for deep foundation application. It was reported that a lower cost SCC and SCHPC can be produced by replacing up to 50% of OPC with SCM such as FA, GGBFS and LSP. Conclusively, the incorporation of these SCMs in binary (two components), ternary (three components) or quaternary (four components) blends, can enhance the rheological characteristics, provide excellent compressive strength values at an early ages and decrease material cost. Consequently, a ternary blend of OPC, POFA and PBC could be used to produce SCHP with excellent attributes.

The development of SCC and the initial mix design method that was proposed by Ozawa, *et al.* (1994), which was later improved by the contribution of Ouchi, *et al.* (1998.) was an important milestone in the history of concrete technology. Furthermore, various guidelines were proposed by JSCE (1999), EFNARC (2002) and ACI237R-07 (2007) which served as the basis for acceptance and general application of SCC and SCHPC. However, due the disadvantages associated with the early mix design processes, various modifications were made so as to accommodate variations in the composition and properties of the constituent materials most especially the SCMs (Dinakar, *et al*, 2013; Ge, *et al*., 2012; Li *et al*., 2012; Mathew & Paul, 2012; Nepomuceno, *et al*., 2012).

Subsequently, statistical models were designed to simplify the test protocols required to optimise mix proportions (Ammar, *et al*., 2012; Sebaibi, *et al*., 2013; Sonebi, 2004). Invariably, most of the models were based on data generated from a given set of materials and correlations, which cannot be generalised to other materials. Thus, there is a need to establish new correlations as new materials are evolving (Nepomuceno, *et al*., 2012). The addition of POFA into SCHPC improves the strength and durability characteristics up to 20% replacement. But any addition in excess of 20% induces segregation and bleeding (Safiuddin, *et al*, 2013). On the other hand, the addition of PBC into SCHPC, improves the rheological properties up to 37.5% replacement level while the compressive strength decreases progressively as the percentage replacement increases from 12.5 to 37.5% (Ge, *et al*., 2012; Heikal, *et al*., 2013). Notwithstanding, an improvement in the densification of the microstructure was observed.

The quest for developing alternative cementitious materials cannot be over emphasized in the face of the dramatically changing economic realities, carbon blueprint and the need for a sustainable eco - system. The challenge, therefore is not only to source alternative cementitious materials, but a great deal of research is required so as to solve major and significant processing and reactivity issues, with a view to establishing the durability of concretes made from such cements. To justify the use of these potentially more carbon dioxide-efficient technologies on a large scale and to have global impact, there is the need to develop adequate performance data that will warrant changes to construction codes and standards.

1.3 Statement of the problem

NVC has been known to have durability problems that are in most cases associated with inadequate compaction. Consequently, replacing it with SCHPC in areas where durability is the primary consideration is a viable alternative. Interestingly, SCHPC is usually associated with high cost due to the use of large amount of powder, thereby necessitating research into cheaper and viable options or substitutes. Consequently, generation of industrial waste such as POFA, PBC, FA, RHA and SF in commercial quantity has prompted research in that direction. Hence there is the need to investigate the performance of the SCHPC due to the incorporation of industrial waste materials such POFA and PBC.

SCHPC requires a sophisticated mix design process so as to achieve the required fresh and hardened properties. Also, the inclusion of different types of SCM has necessitated the development of different mix design procedures so as to cater for the variability in the physical, chemical and microstructural characteristics of these SCMs. In view of the aforementioned problem, there is the need to investigate the physical, chemical and microstructural characteristics of POFA and PBC and hence develop an appropriate mix design process.

It has been advocated that the addition of POFA into SCHPC improves the strength and durability characteristics up to 20% replacement. But any addition in excess of 20% induces segregation and bleeding. On the other hand, the addition of PBC into SCHPC, improves the rheological properties up to 37.5% replacement level while the compressive strength decreases progressively as the percentage replacement increases from 12.5 to 37.5%. It is therefore necessary to investigate the following;

1. The effect of blended POFA and PBC on the fresh properties (filling ability, passing ability and segregation resistance) of the SCHPC system.
2. The influence of blended POFA and PBC on the mechanical, deformation and durability characteristics of the SCHPC system.

1.4 Aim and Objectives of the Study

This research work aims at the development of self-consolidating high performance concrete (SCHPC) incorporating blends of POFA and PBC as supplementary cementing materials. The specific objectives are as follows:

1. Assess the microstructure and Physio-chemical characteristics of POFA obtained from palm oil mill and PBC obtained from clay brick factory.

2. Develop a mix design procedure for the proportioning of materials for the blended SCHPC.

3. Evaluate the fresh properties of the blended self-consolidating paste, mortar and SCHPC.

4. Assess the hardened properties of the blended self-consolidating systems.

5. Evaluate the morphologies and carry out thermal analysis of the blended SCHPC systems.

1.5 Research Questions

The research seeks to address the following questions:

1. What is the effect of the microstructure, mineralogical composition and physical characteristics of the SCMs on the fresh and hardened properties of the SCHPC systems?
2. Does the mix design procedure play any significant role in shaping the performance of the SCHPC systems?
3. Is there any significant relationship between the performance of the paste and mortar components of SCHPC system and the parent concrete?

4. Can the blend of palm oil fuel ash and pulverised burnt clay be used as partial replacement of Ordinary Portland cement to produce a workable, high strength, durable and sustainable concrete?
5. What effect does the blend of POFA and PBC have on the hydration and microstructure of the bulk paste matrix of the SCHPC?

1.6 Scope of the Research

Although this research work focuses primarily on the development of a ternary blended SCHPC containing blended POFA and PBC at replacement levels of 5/5%, 10/5%, 10/10% and 15/15% of ordinary Portland cement (OPC). POFA and PBC were both used basically as supplementary cementing material (SCM) for the production of SCHPC. Diagnostic properties of the constituent concrete materials including their microstructural behaviour were investigated. Thus, a substantial number of intensive investigations and analysis were executed as mentioned below. These investigations are a representative of the research scope and are limited only to concrete applications.

The first phase deals with the preparation and testing of the physical properties of the cementing materials. These include; visual inspection, specific gravity (SG), 45µm wet sieving, 75µm and 150µm dry sieving, pozzolanic activity index, specific surface area by Brunauer Emmet and Teller (BET), particle size distribution (PSD) and loss on ignition (LOI). It also deals with the determination of the chemical properties of the cementing materials (Binder) by X-ray fluorescence (XRF), the determination of the degree of amorphousness of the SCM by X-ray diffraction (XRD). Furthermore, it also covers the determination of the morphological and microscopic features of the SCM through a scanning electron microscope (SEM) and energy dispersive X-ray analysis.

The second phase deals with the mix design and proportioning of the constituent materials for paste, mortar and concrete. It also deals with optimization process for the fresh properties of paste mortar and concrete. These include optimum content of HRWR and appropriate W/B.

The third phase deals with the evaluation of fresh properties, strength, deformation and durability characteristics of paste, mortar and concrete. This includes the flowing ability, passing ability, segregation resistance, compressive, indirect tensile and flexural strengths, fire resistance, rapid chloride ion penetration, electric resistivity, ultrasonic pulse velocity (UPV), drying shrinkage and resistance to acids and sulphates.

The fourth phase deals with the SEM, EDX, XRD, TGA and DTA of the hydrated binder pastes matrix.

1.7 Significance of Study

1. Since SCHPC consumes high volume of binder, the use of high volume of POFA and PBC will result in a reduction of the amount of waste generated from Palm oil mills and clay bricks factory, construction site or demolition site.
2. By replacing the appropriate volume of ordinary Portland cement (OPC) with POFA and PBC, mechanical, deformation and durability properties of SCHPC could be greatly improved.
3. By utilising POFA and PBC as SCM in the production of SCHPC, the mandate of the Kyoto protocol on reducing the CO2 emission may be realised.
4. Since both POFA and PBC are industrial waste materials requiring minimal expenditure, their use will greatly reduce the overall construction cost, thereby justifying the name “Green Concrete”.
5. The use of OPC, POFA and PBC for the production of ternary self-consolidating high performance concrete will open up new research opportunities.

1.8 Thesis organization

The research was prepared and documented in line with the provisions stipulated in the UTM thesis manual, July 2007. Thus, the thesis was designed to consist of eight chapters.

Chapter 1 Provides an introduction of the study area, provides an overview of the problem background to buttress the problem statements, this chapter also highlights the aim and the objectives of the research, as well as highlight the research methodology. The scope and the limitation of the research were clearly spelt out. This chapter also highlights the significant contribution of the research.

Chapter 2 Deals with the critical review of the relevant and related literatures.

Chapter 3 This chapter provides a complete and comprehensive breakdown of the chronological sequence of the methodology that is employed for successful completion of the research from the design stage of the experiment to its logical conclusion.

Chapter 4 This chapter focuses on the characterisation of the constituent materials, including the physical properties, chemical composition and the microstructural characteristics. This chapter also deals with the mix design of the self-consolidating high performance concrete (SCHPC), and the evaluation of the fresh properties of the paste and mortar components, including slump flow time, flow spread, water demand of supplementary cementing materials and saturation dosage of the high range water reducing admixture.

Chapter 5 This chapter deals with the determination of the fresh properties SCHPC and its relationship with the paste and mortar components. These include passing ability, filling ability and segregation resistance.

Chapter 6 This chapter deals with the determination of the hardened properties of the self-consolidating high performance ternary blended systems, including the mechanical, deformation and durability properties.

Chapter 7 This chapter deals with the evaluation of the Morphologies and Thermal Analysis of SCHPC systems.

Chapter 8 This chapter deals with the conclusion and recommendations based on the research findings.

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