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THE PROPERTIES AND FLEXURAL BEHAVIOUR OF SELF COMPACTING CONCRETE USING PALM OIL FUEL ASH AND ADMIXTURE

AZHARIE EFFENDDY BIN AZMI

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
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APRIL, 2008

I declare that this project report entitled "*The Properties and Flexural Behaviour of Self Compacting Concrete using Palm Oil Fuel Ash and Admixture*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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To my beloved Father & Mother

Azmi bin Hj Zaman & Zinab binti Mohd Tab

To my beloved Wife & Children

Tusiah binti Musa
&
Amyra Haziera

Amir Haqimi

ACKNOWLEDGEMENTS

In preparing this project report, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my supervisor, Associate Professor Dr. A.Aziz Saim for his encouragement, guidance, critics, friendship and help during the development of this project report. I am especially grateful for his assistance in providing me with ample reference materials at the early stage of this study.

I am also indebted and very thankful to the management of Sika Kimia Sdn Bhd, especially to Mr. Kathiravan Subramaniam, the Technical Manager for Admixtures Department, for his cooperation and assistance in supplying the one of the most important component in this research, the admixture of Sika ViscoCrete-15RM.

I would also like to express my gratitude and thanks to my wife, Tusiah Musa, for her constant encouragement and advice. This project would not have been possible without her love and support.

Lastly, my sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. Thanks to all for helping me either directly or indirectly in the completion of this report project

ABSTRACT

This research was implemented to develop and to determine the properties and flexural behaviour of Self Compacting Concrete (SCC) by using Palm Oil Fuel Ash (POFA) and admixture (Sika ViscoCrete-15RM). Laboratory test was carried out to investigate the properties of fresh SCC and the strength development of hardened SCC. Six composition of design mix were prepared and tested. The performance of the fresh SCC mixes was determined by testing the filling ability, passing ability, and resistance to segregation characteristics. The properties of fresh SCC mixes were examined through slump flow test, slump flow T_{50} test, L-box test and sieve stability test. The compressive strength test was carried out at the ages of 1, 7, 28 and 56 days to examine the strength development of hardened SCC mixes. Two types of comparable reinforced concrete beams with similar reinforcement and design strength were cast and tested for flexural behaviour comparison between the optimum mix of SCC and normal concrete. The results indicate that POFA and Sika ViscoCrete-15RM are suitable to be used together in producing SCC. The properties and strength development of the produce SCC fulfilled the requirements to be classified as SCC. The SCC also shows higher compressive strength as compared to normal concrete. The flexural strength of the SCC beam indicates a comparable behaviour to normal concrete beam at lower loads. However, the SCC beam achieves higher ultimate strength and showed large ductile behaviour compared to normal concrete beam.

ABSTRAK

Kajian ini dilaksanakan bagi menghasilkan dan mengenalpasti sifat-sifat serta kelakuan lenturan bagi konkrit tanpa mampatan (SCC) dengan menggunakan Abu Pembakaran Kelapa Sawit (POFA) dan bahan tambah (Sika ViscoCrete-15RM). Sifat-sifat serta perkembangan kekuatan bagi SCC ketika basah dan setelah mengeras ditentukan melalui ujian makmal. Enam jenis campuran rekabentuk disediakan dan diuji. Prestasi SCC ketika basah dikenalpasti dengan menguji sifat kebolehannya mengisi ruang, melepasi halangan dan rintangan terhadap pengasingan. Sifat-sifat campuran SCC ketika basah diuji melalui ujian serakan, ujian serakan pada T_{50}, ujian kotak-L dan ujian kestabilan ayakan. Kekuatan mampatan konkrit diuji pada umur 1, 7, 28 dan 56 hari bagi menentukan perkembangan kekuatan bagi SCC setelah mengeras. Dua jenis rasuk konkrit bertetulang yang sepadan, terdiri daripada campuran SCC yang optimum dan konkrit biasa dengan besi tetulang serta rekabentuk kekuatan mampatan yang sama, dihasilkan dan diuji untuk perbandingan kelakuan lenturannya. Keputusan kajian menunjukkan penggunaan POFA dan Sika ViscoCrete-15RM adalah bersesuaian bagi menghasilkan SCC. Sifat-sifat, perkembangan kekuatan serta kelakuan lenturan bagi SCC yang terhasil memenuhi keperluan untuk dikelaskan sebagai SCC. SCC yang terhasil juga menunjukkan kekuatan dan prestasi yang tinggi berbanding dengan konkrit biasa. Kekuatan lenturan bagi rasuk SCC menunjukkan perbandingan kelakuan yang hampir sama dengan rasuk konkrit biasa di peringkat awal pembebanan. Walau bagaimanapun, rasuk SCC telah mencapai kekuatan muktamad yang tinggi dan menunjukkan sifat keanjalan yang besar berbanding dengan rasuk konkrit biasa.

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LIST OF ABBREVIATIONS

SCC	–	Self Compacting Concrete
NC		Normal Concrete
POFA	–	Palm Oil Fuel Ash
OPC	–	Ordinary Portland Cement
w/b	–	Water-binder
pfa	–	Pulverized Fly Ash
ggbs	–	Ground Granulated Blast-furnace Slag
csf	–	Condensed Silica Fume
VMA	–	Viscosity Modifying Admixture
HRWR	–	High Range Water Reducing
QC	–	Quality Control
QA	–	Quality Assurance
SF	–	Slump Flow
HPC	–	High Performance Concrete

LIST OF SYMBOLS

E	–	Modulus of elasticity.
f_{cu}	–	Compressive strength.
M_a	–	The difference between the weights full and empty.
M_b	–	Mass of sample passing sieve.
W_p	–	Pan weight.
W_s	–	Sieve weight.
W_r	–	Residual weight.
P_{cr}	–	Load at 1st cracking.
δ_{cr}	–	Deflection at 1st cracking.
P_y	–	Load at 1st yield of steel.
δ_y	–	Deflection at 1st yield of steel.
P_{ult}		Ultimate load.
δ_{max}		Maximum deflection.
M_c		Calculated moment capacity.
v_c		Calculated shear capacity.
M_{act}		Actual moment capacity.
v_{act}		Actual shear capacity.

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is the most widely consumed material in the world, after water. Nowadays, most of the construction for buildings and infrastructures in Malaysia are using concrete as construction material. Concrete is the only major building material that can be delivered to the job site in a plastic state. This unique quality makes concrete desirable as a building material because it can be molded to virtually any form or shape and can be used to construct a wide variety of structures.

Self Compacting Concrete (SCC), a recent innovation in concrete technology, has numerous advantages over normal concrete. Self-compacting concrete, as the name indicates, is a type of concrete that does not require external or internal compaction, because it becomes leveled and compacted under its self-weight. SCC can spread and fill every corner of the formwork, purely by means of its self-weight, thus eliminating the need of vibration or any type of compacting effort.

SCC has been in the market place for some time. This type of high-performance concrete has been in use only since the late 1980s. Professor Hajime Okamura (University of Tokyo, now Kochi Institute of Technology) advocated the use of SCC in 1986 for the first time in the world and has been spread to all over the world as the original of Japan. The first prototype was developed in 1988 as a response to the growing problems associated with concrete durability and the high demand for skilled workers.

Since the development of the prototype of SCC in 1988, the use of SCC in actual structures all over the world has gradually increased. The main reasons for the employment of SCC are to shorten construction period, to assure compaction in the structure and to eliminate noise due to vibration. That means the current condition of SCC is a “special concrete” rather than normal concrete.

By employing SCC, the cost of vibrating compaction can be saved and the compaction of the concrete in the structure can be assured. SCC can greatly improve construction systems which previously based on conventional concrete where vibrating compaction is required. A new construction system, including formwork, reinforcement, support and structural design also can be developed to suite the advancement in this type of concrete.

Modern application of SCC is focused on high performance which better and more reliable quality, dense and uniform surface texture, improved durability, high strength and faster construction. The application of SCC in Malaysian construction sector is still new and limited in precast concrete industry and geotechnical works. Therefore, a lot of further research on this type of concrete technology needs to be carried out to enhance our nation capability and quality in constructing building and other infrastructures.

1.2 Problem Statement

The increasing demand for high performance concrete which use new technique and new material have encouraged this research to be conducted. The usage of POFA in this aspect of research is still new. The research implementation is to study and determine the compatibility of Palm Oil Fuel Ash (POFA) as cement replacement material and Sika ViscoCrete-15RM as an admixture to produce SCC. Hopefully this research can contribute to the other findings in developing SCC and can be applied in our local construction industry.

1.3 Research Aim and Objectives

The aim of this research is to produce a suitable concrete compound which can be categorized as SCC that using POFA as cement replacement material together with Sika ViscoCrete-15RM as admixture. The compatibility of both material bind together also will be observed.

The objectives of this research being conduct are:

(i) To develop and produce SCC using Palm Oil Fuel Ash and Sika ViscoCrete-15RM.
(ii) To investigate the properties and strength development of SCC.
(iii) To compare the flexural behavior of reinforced concrete beam of SCC and normal concrete.

1.4 Research Scope

In executing the research, the scope boundary needs to be defined and a few limitation factors to be drawn to avoid a very wide scope of research and unfocussed study. The scope and limitation factors for this research are:

(i) The mixtures of SCC are only using POFA as cement replacement material and Sika ViscoCrete-15RM as admixture.
(ii) The developments for the proposed SCC mix are only using Ordinary Portland Cement (OPC).
(iii) The water- binder ratio (w/b) for all the mixes is fixed to 0.36.
(iv) The comparison in flexural behaviour aspect only involves the most optimum design mix of SCC to be compared with normal concrete.

1.5 Research Significance

The advantages of SCC are already recognized by the concrete industry. Design and construction specifications are urgently needed to give the designers another option in meeting the demands of today and tomorrow for high performance concrete in the construction.

From the research, clearer picture and differences between SCC and normal concrete can be observed and understood. There will be high payoff in not requiring vibration to achieve compaction and the low noise level to meet stringent environmental requirements in urban and suburban construction. Less labour and speedier construction will result in substantial cost savings, less traffic disruption and risk reduction.

The use of POFA as cement replacement material in SCC will fully utilize this natural resources instead of becoming an industrial waste material only. The replacement can reduce the cost of concrete since the increasing in cement price and at the same time to reduce the huge amount of palm oil industry waste material that being produced.

SCC using POFA has good potential for greater acceptance and wider applications in civil infrastructure works in Malaysia and other part of the world. Hopefully, this research can guide the civil engineering community and the concrete industry to take advantage of a new breed of SCC.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Self compacting concrete (SCC), also been described and known as concrete without vibration, self consolidating concrete, self placing concrete and self leveling concrete, is a highly flowable, non-segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical compaction. As a high-performance concrete, SCC delivers these attractive benefits while maintaining all of concrete's customary mechanical properties and durability characteristics.

SCC has been described as "*the most revolutionary development in concrete construction for several decades*" [1]. Originally developed to offset a growing shortage of skilled labour, it has proved beneficial economically because of a number of factors, including:

(i) Faster construction.
(ii) Reduction in site manpower.
(iii) Better surface finishes.
(iv) Easier placing.
(v) Improved durability.
(vi) Greater freedom in design.
(vii) Thinner concrete sections.
(viii) Reduced noise levels, absence of vibration.
(ix) Safer working environment.

SCC's unique properties give it significant economic, constructability, aesthetic and engineering advantages. SCC is an increasingly attractive choice for optimizing site manpower through reduction of labor and possibly skill level, lowering noise levels, and allowing for a safer working environment. SCC allows easier pumping even from bottom up, flows into complex shapes, transitions through inaccessible spots, and minimizes voids around embedded items to produce a high degree of homogeneity and uniformity. That's why SCC allows for denser reinforcement, optimized concrete sections and shapes, and greater freedom of design while producing superior surface finishes and textures.

2.2 Self Compacting Concrete

Self Compacting Concrete (SCC) was first developed in Japan since the late 1980s in order to reach durable concrete structures. Since then, several investigations have been carried out to achieve a rational mix design for a standard concrete, which is comparable to normal concrete. SCC is defined so that no additional inner or outer vibration is necessary for the compaction. SCC is compacting itself alone due to its self-weight and is deaerated almost completely while flowing in the formwork. In structural members with high percentage of reinforcement it fills also completely all voids and gaps. SCC flows like “honey” and has nearly a horizontal concrete level after placing.

With regard to its composition, SCC of the same components as conventionally vibrated normal concrete which are cement, aggregates, water, additives and admixtures. However, the high amount of superplasticizer for reduction of the liquid limit and for better workability, the high powder content as “lubricant” for the coarse aggregates, as well as the use of viscosity-agents to increase the viscosity of the concrete have to be taken into account. **Figure 2.1** shows the comparison of mix proportioning between normal concrete and SCC [2].

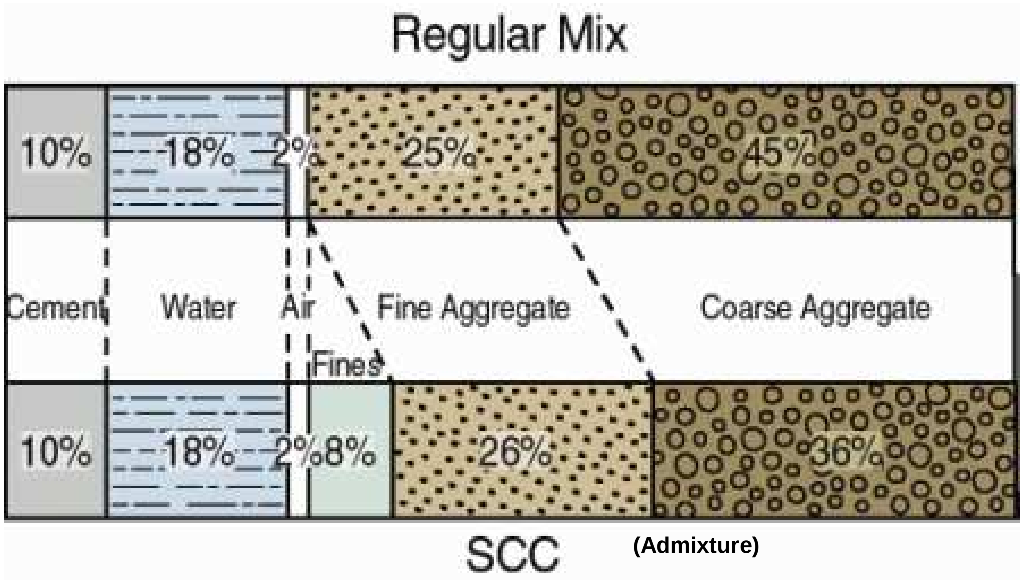

Figure 2.1 : Comparison of mix proportioning between normal concrete and SCC.[2]

In principle, the properties of the fresh and hardened SCC, which depend on the mix design, should not be different from normal concrete. One exception is only the consistency. **Figure 2.2** shows the basic principles for the production of SCC [3].

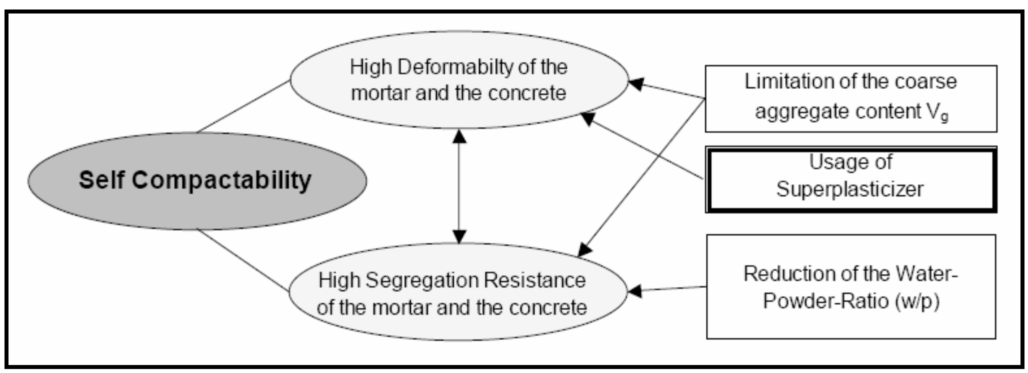

Figure 2.2 : Basic principles for the production of SCC.[3]

SCC looks very different from conventional concrete while mixing. Concrete producers must "retrain their eyes" for this very fluid mixture as it turns corners and fills forms. Traditionally, concrete with the fluidity of SCC has had a very high water-to-cement ratio, which would lower compressive strengths and compromise durability. Properly designed SCC can save time and labour without sacrificing performance. SCC mixes must meet three key properties as follows:

(i) **Filling ability** – the ability of the concrete to flow freely under its own weight, both horizontally and vertically upwards if necessary, and to completely fill formwork of any dimension and shape without leaving voids.

(ii) **Passing ability –** the ability of concrete to flow freely in and around dense reinforcement without blocking.

(iii) **Resistance to segregation** – during placement and while flowing, the concrete should retain its homogeneity. There should be no separation of aggregate from paste or water from solids, and no tendency for coarse aggregate to sink downwards through the fresh concrete mass under gravity.[4]

As an engineered concrete, SCC offers characteristics that engineer's value. Improved constructability to produce homogeneous and uniform concrete allows for higher reliability in design assumptions. Engineering properties and their inter-relationships remain unchanged from those of conventional concrete and any differences are adequately addressed by conservatism in the design codes. The principles of concrete durability with respect to reduced permeability, resistance to freezing and thawing and sulfate attack, alkali-aggregate reactions, thermal stresses and corrosion protection of reinforcement also apply similarly to SCC. SCC's superior rheology allows for the design and construction of complex shapes with congested reinforcement, and its non-segregating qualities are important for deep-section or long-span applications. The fluidity of SCC can be engineered in terms of its viscosity, both the rate and degree of flow, to allow for a wider variety of placement and construction means and methods.

2.3 Cement Replacement Materials

Cement replacement materials are special types of naturally occurring materials or industrial waste products that can be used in concrete mixes to partially replace some of the Portland cement. Cement replacement materials are frequently called fine minerals or pozzolans. Surprisingly, concrete with cement replacement materials can actually be stronger and more durable than concrete with ordinary Portland cement (OPC).

The three most-commonly used cement replacement materials are the pulverized fly ash (pfa), ground granulated blast-furnace slag (ggbs) and condensed silica fume (csf).

Fly ash is a fine, glass-like powder recovered from gases created by coal-fired electric power generation. Power plants produce a huge amount of fly ash annually, which is usually dumped in landfills. Fly ash is an inexpensive replacement for Portland cement used in concrete, while it actually improves strength, segregation, and ease of pumping of the concrete. Fly ash is also used as an ingredient in brick, block, paving, and structural fills.

Fly ash concrete was found that it allowed for less total cement. Consisting mostly of silica, alumina and iron [5] as shown in **Table 2.1**, fly ash is a pozzolan, a substance containing aluminous and silicious material that forms cement in the presence of water. When mixed with lime and water it forms a compound similar to Portland cement. The spherical shape of the particles reduces internal friction thereby increasing the concrete's fluidity, permitting longer pumping distances. Improved workability means less water is needed, resulting in less segregation of the mixture. Although fly ash cement itself is less dense than Portland cement, the produced concrete is denser and results in a smoother surface with sharper detail.

Table 2.1 : Percent composition of cement replacement materials by mass.[5]

Oxide	pfa		ggbs	csf	Portland cement (Type I)
	Low lime	High lime			
SiO_2	48	40	36	97	20
Al_2O_3	27	18	9	2	5
Fe_2O_3	9	8	1	0.1	4
MgO	2	4	11	0.1	1
CaO	3	20	40		64
Na_2O	1	--	--		0.2
K_2O	4	--	--		0.5

Ground granulated blast-furnace slag (ggbs) is the granular material formed when molten iron blast furnace slag is quenched. It is a granular product with very limited crystal formation is highly cementitious in nature and, when ground to cement fineness, hydrates like Portland cement. Blast furnace slag cement is made by intergrinding the granulated slag with Portland cement clinker (blended cement).

Condensed Silica Fume (csf) also known as microsilica, is a byproduct of the reduction of high-purity quartz with coal in electric furnaces in the production of silicon and ferrosilicon alloys. Silica fume is also collected as a byproduct in the production of other silicon alloys such as ferrochromium, ferromanganese, ferromagnesium, and calcium silicon.

Silica fume consists of very fine vitreous particles approximately 100 times smaller than those of ordinary cement particles, and with a surface area of 20,000m^2/kg [5] as shown in **Table 2.2**. Because of its extreme fineness and high silica content, csf is a highly effective pozzolanic material. It has been found that csf: improves compressive strength, bond strength, and abrasion resistance; reduces permeability; and therefore helps in protecting reinforcing steel from corrosion.