

**INFLUENCE OF PALM OIL FUEL ASH AS A SUPPLEMENTARY
BINDER ON PROPERTIES OF SELF-COMPACTING CONCRETE**

by

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**PENGARUH ABU SISA KELAPA SAWIT SEBAGAI PEREKAT
TAMBAHAN TERHADAP SIFAT-SIFAT KONKRIT TERPADAT
SENDIRI**

oleh

ZAINURUL BINTI ZAINUL

**Tesis yang diserahkan untuk
memenuhi keperluan bagi
Ijazah Sarjana Sains**

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LIST OF ABBREVIATIONS

ASTM	American Society of Testing and Materials
BET Apparatus	Brunauer, Emmetl, and Teller Apparatus
BS	British Standard
BS EN	British European Standards Specifications
C	Coulombs
Ca(OH) ₂	Calcium Hydroxide
C-S-H	Calcium Silicate Hydrate
GPOFA	Ground Palm Oil Fuel Ash
HSGC	High Strength Green Concrete
ISAT	Initial Surface Absorption
LOI	Loss of Ignition
MPa	Mega Pascal
NVC	Normal Vibrated Concrete
OPC	Ordinary Portland Cement
POFA	Palm Oil Fuel Ash
RCMT	Rapid Chloride Migration Test

RCPT	Rapid Chloride Permeability Test
SCC	Self -Compacting Concrete
SiO ₂	Silicon Oxide
XR-D	X-Ray Diffraction
XR-F	X-Ray Fluorescence

PENGARUH ABU SISA KELAPA SAWIT SEBAGAI PEREKAT TAMBAHAN TERHADAP SIFAT- SIFAT KONKRIT TERPADAT SENDIRI

ABSTRAK

Abu sisa kelapa sawit (POFA) yang diperolehi daripada kilang minyak sawit telah dikenakan proses rawatan yang melibatkan ayakan, pengisaran dan rawatan haba untuk menghaluskan saiz zarah dan meningkatkan potensi kereaktifannya sebagai bahan pozzolana di dalam konkrit terpadat sendiri (SCC). POFA yang telah dirawat kemudiannya digunakan sebagai bahan gantian separa simen di dalam SCC dengan kandungan POFA sebanyak 0%, 20%, 40% dan 60% daripada jisim simen Portland biasa (OPC). Sifat-sifat awal campuran SCC telah dikaji melalui aliran terunam, aliran kemerosotan T_{500} , ujian kotak -L, ujian kestabilan ayakan serta ujian masa pemejalan konkrit dengan penggunaan POFA pada tahap penggantian 60% memberi keputusan yang optimum serta kesemuanya mematuhi syarat yang telah ditetapkan untuk SCC. Sebaliknya, sifat-sifat SCC terkeras telah dinilai melalui ujian kekuatan mampatan, ujian keliangan, penyerapan awal permukaan (ISAT), kebolehtelapan gas, ketelapan air, kebolehtelapan klorida pesat (RCPT) dan penghijrahan klorida pesat (RCMT). Keputusan yang diperolehi mempamerkan peningkatan yang ketara pada sifat-sifat SCC dengan penggunaan POFA. Penggunaan POFA sebanyak 40% mempamerkan nilai kekuatan mampatan yang paling tinggi dan melebihi kekuatan sasaran 50 MPa. Dari segi sifat-sifat berkaitan ketahananlasakan, kesemua campuran SCC-POFA mempamerkan sifat-sifat yang lebih baik daripada OPC-SCC, dimana campuran yang mengandungi 60% POFA mempamerkan peningkatan tertinggi pada 180 hari tempoh pengawetan air untuk semua ujian. Oleh itu, keputusan keseluruhan kajian membuktikan bahawa penggunaan POFA dalam SCC menawarkan peningkatan prestasi terhadap sifat-sifat

awal dan sifat-sifat terkeras SCC, di samping menggalakkan pengekatan kehijauan alam sekitar dengan berkurangnya kadar penggunaan simen.

INFLUENCE OF PALM OIL FUEL ASH AS SUPPLEMENTARY BINDER ON PROPERTIES OF SELF-COMPACTING CONCRETE

ABSTRACT

Palm Oil Fuel Ash (POFA) obtained from a palm oil mill was subjected to treatment process via sieving, grinding and heat treatment in order to improve its particles size and its potential reactivity as pozzolanic material in self-compacting concrete (SCC). The treated POFA was then utilized as partial cement replacement in the production of SCC with POFA contents of 0%, 20%, 40% and 60% by mass of Ordinary Portland Cement (OPC). The properties of fresh SCC mixes were explored through slump flow, slump flow T_{500} , L-box, sieve stability as well as proctor penetration tests where the inclusion of POFA at replacement of 60% gave excellent results which satisfied the stipulated requirement for SCC. On contrary, the hardened properties of SCC was evaluated through compressive strength, porosity, initial surface absorption (ISAT), gas permeability, water permeability, Rapid Chloride Permeability (RCPT) and Rapid Chloride Migration (RMT) tests. The results obtained indicated significant improvement in the hardened SCC properties with the inclusion of POFA. SCC with 40% POFA exhibits the greatest compressive strength value which exceeded the targeted strength of 50 MPa. In term of durability related properties, all POFA-SCC mixes showed better properties than the OPC-SCC, where the mix containing 60 % POFA exhibiting the greatest improvement at 180 days of water-curing period for all tests. Hence, the overall results establish that utilization of POFA in SCC offers for better performance in terms of both fresh and hardened properties of SCC, while promoting for green environment due to the less cement usage.

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is the most extensively used construction material and it generally consists of a binding medium comprising of cement, and water, called the cement paste that are mixed with particles of inert filler consisting of sand and crushed rock (Neville and Brooks, 2008; Gupta and Gupta, 2004; Nawy et al., 2008; Chudley and Greeno, 2006). The reasons for concrete to become the most widely used construction material include its ability which possesses excellent resistance to water. The ability of concrete to withstand the action of water without serious deterioration makes it an ideal material for building structures to control, store and transport water. Moreover, structural concrete elements can be formed into various shapes and sizes as well as the ingredients for producing concrete are relatively cheap and most readily available material in comparison to other construction materials. In addition, concrete can be engineered or tailor made to have special characteristics. Some of the special concrete includes High Strength Concrete (HSC), Polymer Concrete, Fiber Reinforced Concrete (FRC) and Self-Compacting Concrete (SCC). The term commonly used to describe SCC in North America is ‘Self-Consolidating Concrete’.

Self-Compacting concrete (SCC), a recent innovation in concrete technology, has numerous benefits compared to Normally Vibrated Concrete (NVC). SCC can be considered as a concrete that can be placed and compacted under its own self-weight with little or no vibration effort, and which at the same time is cohesive enough to be handled without segregation or bleeding. It can also be defined as fresh concrete, which possesses superior flowability under maintained stability, which is without

segregation, thus allowing self-compaction whereby the material is compacted without additional of energy. According to Khayat (1999), SCC can be defined as a highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing any significant separation. The development of SCC was first taken place in Japan, in 1988 in order to achieve durable concrete structures by improving quality in the construction process. It was found to contribute not only to economic and social but it also bring about environmental advantages over NVC construction. The other benefits of SCC include faster construction time and elimination of noise due to vibration. It also requires less skilled labour compared to NVC in order to produce uniformly dense concrete.

On the other hand, unlike NVC, SCC does not require compaction using external force from mechanical equipment such as immersion vibrator; instead, SCC is designed in such way in order for it to get compacted using its own weight. Compaction is the key to producing good concrete with favourable strength and durability (The Concrete Society and BRE, 2005). The hardened SCC is dense, homogenous and has the same hardened properties as NVC. SCC requires higher amount of powder admixture especially superplasticizer contents than NVC and thus, cause high in material cost (The Concrete Society and BRE, 2005). Nonetheless, in the construction of very large structures, the increased material cost by using SCC could be compensated by saving in labour costs and construction time (Billberg, 1999).

SCC achieves this self-compacting ability by its unique fresh state properties. Basic requirements for SCC are those in the fresh state, which are filling ability (flowing ability), passing ability (flow without blocking) and segregation resistance.

A concrete mix can only be classified as SCC if the requirements for all three characteristics are fulfilled. SCC mixes generally have a much higher content of fine fillers including cement and produce excessively high compressive strength concrete, which restricts its field of application to special concrete only. As mentioned before, SCC requires higher powder and admixture content especially superplasticizer contents than NVC and thus, causes higher in cost (The Concrete Society and BRE, 2005). Therefore, the introduction of SCC by partially replacing cement with supplementary cementitious material is necessary in order to promote not only economic advantages but also environmental friendliness.

Nowadays, concrete containing natural or artificial pozzolans had been used extensively due to their contribution towards good durability performance, economic advantages and environmental friendliness. For the past few years, the use of by-product materials including agricultural wastes has been investigated by many researchers. Wastes such as fly ash, silica fume, rice husk ash just to list a few were studied in order to assess their suitability to be used as new supplementary binder for environmental and economic purposes (Miao, 2010; Memon et al., 2008; Chindaprasirt et al., 2007; Turkmen, 2003; Bouzoubaa et al., 2000). Thus, the finding of the alternative conventional building material that is cheaper, accessible and does not cause harm towards the environment has created greater interest amongst the researchers as it can promote for green concrete as well reduce the percentage of wastes requiring land filling.

In Malaysia, Palm Oil Fuel Ash (POFA), ash residue from burning of palm kernel shells, empty fruit bunches and fibers has begun to gain attention for its feasibility to replace a certain proportion of cement in the production of concrete. Malaysia is well known as the second largest producer of palm oil which produces

around 17.7 million tonnes of palm oil from 4,500,00 hectares of palm oil plantation (MPOB, 2009). Consequently, the proliferation of palm oil industry may lead to substantial and often irreversible damage to the future natural environment such as increase in green house gas emissions and high rate of landfill due to the restricted utilization of waste materials. Therefore, appropriate measures and efforts are required with regards to waste reduction so that future sustainability and environmental friendliness could be preserved.

Previous studies have proven that POFA fulfilled the requirement of ASTM C618-05 (2005). According to ASTM C618-92a (2005), pozzolanic material can be defined as siliceous or siliceous and aluminous material which in itself possesses little or no cementitious properties, but which will in finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compound possessing cementing properties. As mentioned before, POFA is from agro waste ashes whereby its chemical composition contains a large amount of silica and thus, is highly capable to act as a partial cement replacement (Tangchirapat et al., 2003). According to Tonayopas et al., (2006), pozzolanic reaction between POFA and cement matrix could have positive effect on the strength development and durability of concrete. In order to extend the use of POFA in concrete, some researchers have utilized up to 40% of POFA as partial Portland Cement replacement (Awal and Hussin, 1997; Sata et al., 2004; Sata et al., 2007) but there have been some limitations of the POFA used as the highest contribution on strength was given at POFA replacement level of 20% to 30%.

Nonetheless, a recent study by Megat Johari et al., (2012) has shown that refined POFA with smaller particles size and reduced carbon content could improve the strength and transport properties of High Strength Green Concrete (HSGC) even

when utilized at higher replacement level of up to 60%. The objective of this present study is to explore the possibility of developing SCC by incorporating high volume of POFA. It focuses on rheological properties of SCC that encompass filling ability, passing ability and segregation resistance, which are important requirements of SCC; as concrete mix can only be classified as SCC if the requirements for all three characteristics are fulfilled. While setting times of SCC had also been evaluated as an additional test that completed the findings in fresh properties of SCC. This research also focuses on hardened properties of SCC including compressive strength; porosity; initial surface absorption; gas and water permeability; rapid chloride permeability and rapid chloride migration. If POFA can improve the strength of SCC, it will encourage other researchers for further investigating the use of POFA in SCC, resulting in higher utilization of POFA and reduction in POFA as waste material. It is part of an on-going research dealing with properties of SCC containing high volume of refined POFA.

As stated before, concrete containing mineral admixture that is used widely throughout the world can promote not only for their good performance and for ecological but also economic reason. The utilization of POFA that possesses pozzolanic properties which enable the replacement of cement in SCC has not been investigated in details unlike fly ash in SCC that has been explored since 1980's. POFA is relatively cheaper than most existing pozzolanic materials, and it may be possible to manufacture SCC incorporating high volume of POFA with higher fineness. The application of SCC in Malaysian construction sector is still new and limited in precast concrete industry and geotechnical works. Nevertheless, further research on this type of concrete technology utilizing POFA needs to be carried out

to enhance our nation capability and quality in the construction of building and other infrastructure.

1.2 Problem Statement

The application of SCC in the Malaysian construction industry is still new compared to Japan and European countries. Moreover, the abundant wastes from palm oil industry had become a major problem towards the environment due to limited reuse and recycle of those waste materials. In this case, the utilization of this waste in the development of SCC would be beneficial as there is a gradually increasing demand of such special concrete with high performance characteristics, which at the same time can minimize the cost by introducing the new method and new material that encourage this research to be conducted. The application of POFA in this aspect of research is still new as previous studies always use fly ash, silica fume, rice husk ash just to list a few. In addition, the available information related to the effect of POFA on properties of SCC is rather scarce or negligible. Thus, the proposed study aims at quantifying the influence of POFA as supplementary binder on properties of SCC.

It is believed that by the incorporation of POFA as partial cement replacement in SCC, it could create a new workable concrete and improve its strength and durability performance, as well as it will lead to reduction of POFA as waste material and solve waste disposal problem. Due to large quantities of palm oil waste disposed every year, the idea to reuse and recycle it in order to prevent from environmental problems becomes a vital research topic. Thus, the aim of this research is to investigate the influence of POFA as a supplementary binder on properties of SCC. This research could optimistically contribute to other finding in developing SCC utilizing POFA which is feasible to not only minimize the cost but

also to promote environmental friendliness by introducing green concrete that is possible to be practiced in our country, specifically the Malaysian construction industry.

1.3 Research Aim and Objectives

The availability of POFA and its pozzolanic properties had been taken into consideration which leads to the formulation of the objectives of this study. The main objective of this present research was to investigate the influence of POFA as supplementary binder in production of a suitable concrete mixture that can be classified as SCC. The objectives of this research are outlined as follows:

- i. To investigate the effectiveness of POFA as a supplementary binder in the production of SCC.
- ii. To evaluate the rheological properties of fresh POFA-SCC (i.e SCC with POFA) by determining its three key properties, which are filling ability, passing ability and resistance to segregation characteristics and compared with OPC- SCC (i.e. SCC without POFA or Control SCC).
- iii. To assess the hardened properties of SCC containing different levels of replacement of POFA.

1.4 Scope of Research

This present research consists of three stages. The first stage was the production of treated POFA in the laboratory via sieving, grinding and heating processes in order to improve its efficiency as pozzolanic material. This stage was necessary in order to produce an appropriate mineral admixture that can be used as partial cement replacement in SCC. In the second stage, it was important to identify and determine the suitable mix design and production procedures for SCC. This was

performed by carrying out trial mixes and performing tests on fresh properties of SCC before the optimum design mix can be obtained. For the third stage, the aim was to fabricate SCC mixes by replacing ordinary Portland Cement (OPC) with POFA on mass-for-mass basis up to 60% rate of replacement.

As mentioned earlier, this research focuses on utilization of POFA at different levels of replacement on the properties of SCC. From a conscientious observation, it was found out that many potential tests can be explored. In this research, the concrete mixture would utilize POFA as a supplementary binder for the production of SCC. Ordinary Portland Cement (OPC) was used as a control to observe the differences between SCC with POFA and SCC without POFA. All the specimens were first tested on their early age in order to identify whether the mixture can be classified as SCC that fulfilled three requirement of SCC followed by hardened properties tests and the results were compared with those of the control specimens. Each mixture with the specific level of replacement of POFA was designed to achieve minimum target strength of 50MPa at the age of 28 days. The scopes of this research are detailed as the followings:

- POFA that was used in this research as supplementary binder in SCC was collected from nearby local Palm Oil Mill, which was in a raw material form. It contains large and coarser particles, which were incompletely burned during combustion and possess low pozzolanic properties. Nevertheless, in order to overcome the problem, POFA was prepared and treated manually in the laboratory in order to generate effective results and to control the quality as well as increasing its efficiency. POFA was subjected to sieving, grinding and heating process, which the final results had improved in its fineness and its reactivity. In addition, characterization of POFA had been conducted in

order to identify the suitability of POFA via XRD, XRF, specific gravity and fineness test.

- The experimental phase of this study included two types of concrete, plain SCC that is recognized as OPC-SCC and SCC containing POFA that is recognized as POFA-SCC with characteristics strength of 50 MPa at 28 days. It is included with Ordinary Portland Cement (OPC) as a binder, crushed granite as coarse aggregates; natural river sand and water were used in the production of the concrete specimens. Furthermore, Sika ViscoCrete-15RM was used in order to provide sufficient water reduction while maintaining acceptable workability in terms of filling ability, passing ability and resistance to segregation as well as setting times.
- In order to establish the suitable mix design of SCC, slump flow and slump flow T_{500} time, L-box test and sieve stability tests were used in order to fulfill three requirements of SCC which include to determine the ability to flow into and completely fill intricate and complex forms under its own weight (filling ability), ability to pass through and bond to congested reinforcement under its own weight (passing ability) and high resistance towards aggregate segregation.
- Testing on concrete specimens were conducted at different level of replacement of POFA, namely 0%, 20%, 40% and 60% in order to determine the influence of POFA as supplementary binder in SCC on the behaviour in terms of rheological properties namely; slump flow, slump flow T_{500} , sieve stability as well as proctor penetration tests. While for hardened properties, the tests performed include compressive strength, water absorption and porosity, ISAT, gas and water permeability, rapid chloride permeability and rapid chloride migration tests.

(POFA-SCC) based on their early age properties and hardened properties were compared.

- The influence of POFA at different levels of replacement namely 0%, 20%, 40% and 60% that is used in SCC as pozzolanic material had been investigated in order to produce the optimum design mix of SCC with POFA as a supplementary binder.

1.5 Importance of Research

Nowadays, SCC is being studied worldwide and is being applied in many countries especially in Japan and European countries. There are many advantages of SCC in concrete industry. By introducing POFA in the production of SCC, it contributed towards sustainability of waste management that can promote environmental friendliness and also reduced the construction costs. It was a brilliant idea to incorporate POFA in SCC to fabricate special concrete with great performance that meets today's demands.

From this research, the idea of dissimilarity between SCC and NVC can be seen clearly and understood. SCC has this kind of ability to completely fill the complex formworks and restricted areas of congested steel reinforcement without any compaction, which at the same time minimize the possibility of voids and honeycombs compared to NVC. SCC improved not only for qualities, but also for productivity and working condition (Miao, 2010; The Concrete Society and BRE, 2005).

SCC also contributed for a less porous transition zones between paste and aggregate due to elimination of compaction which the internal segregation between solid particle and the compaction which the internal segregation between solid

particle and the surrounding liquid is avoided (RILEM TC 174 SCC, 2000). It had a potential for an excellent strength performance, durability and improved surface finishes, as the surface is smooth and dense. On top of that, the influences of POFA as supplementary binder in SCC fully utilizes this agro waste, which encourage for reduction of the huge amount of waste materials that is increasingly generated day-to-day. By reusing and recycling it, it can reduce the cost of concrete in view of the fact that the raising in cement price as well as to promote for environmental friendliness and thus, contribute for green concrete with great strength and durability performance.

As a summary, the utilization of POFA in SCC had many advantages not only for environmental aspects but also for economic reason. It is believed to give a good potential and promises a high quality performance that can be acceptable to be practiced in civil infrastructure works in Malaysia and worldwide. In addition, this research seems to be one of the references that lead the construction community to obtain the usefulness of it that can be applied in concrete industry without any regret and hesitation as it is a new invention for the concrete industry in Malaysia.

1.6 Research Hypothesis

Through this research, it is believed that the change of the percentage of Palm Oil Fuel Ash (POFA), which is at different level of replacement namely 0%, 20%, 40% and 60% as a supplementary binder in the production of SCC had affected the properties of fresh and hardened state of SCC. The suitable amount of POFA to produce an acceptable characteristic of SCC had been determined. Therefore, the potential of POFA as a cement replacement in the production of SCC had been the main factor in this research in order to produce good strength performance and durable SCC.

- The differences results between OPC-SCC and SCC containing POFA (POFA-SCC) based on their early age properties and hardened properties were compared.
- The influence of POFA at different levels of replacement namely 0%, 20%, 40% and 60% that is used in SCC as pozzolanic material had been investigated in order to produce the optimum design mix of SCC with POFA as a supplementary binder.

1.5 Importance of Research

Nowadays, SCC is being studied worldwide and is being applied in many countries especially in Japan and European countries. There are many advantages of SCC in concrete industry. By introducing POFA in the production of SCC, it contributed towards sustainability of waste management that can promote environmental friendliness and also reduced the construction costs. It was a brilliant idea to incorporate POFA in SCC to fabricate special concrete with great performance that meets today's demands.

From this research, the idea of dissimilarity between SCC and NVC can be seen clearly and understood. SCC has this kind of ability to completely fill the complex formworks and restricted areas of congested steel reinforcement without any compaction, which at the same time minimize the possibility of voids and honeycombs compared to NVC. SCC improved not only for qualities, but also for productivity and working condition (Miao, 2010; The Concrete Society and BRE, 2005).

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1.7 Layout of Thesis

Chapter 1 provides the research background, problem statements, objectives as well as the scope of the research.

Chapter 2 evaluates and summarizes the relevant literature on the rheological properties, hardened properties, criteria and mix design of SCC based on the available literatures. A detailed review of POFA as pozzolanic material for use as partial substitute of cement in producing concrete and SCC is also provided.

Chapter 3 explains the research methodology. It portrays and discusses all the constituent materials used in the research. Besides, the mixing procedures, process of treated POFA, test methods for the fresh SCC as well as hardened SCC and method of data evaluation are detailed in this chapter.

Chapter 4 explains and discusses the results on inclusion of POFA on properties of SCC with different level of replacement namely 0%, 20%, 40% and 60%. The test on fresh properties of SCC namely slump flow test, slump flow T_{500} test, L-box test and sieve stability test as well as proctor penetration test were evaluated for the fresh properties of SCC. These mixes were then tested for hardened properties which were compressive strength; porosity, initial surface absorption; gas and water permeability; rapid chloride permeability and rapid chloride migration at ages from 3 days to 180 days. Subsequently, all test results are combined and analyzed. Some correlations established from the results are demonstrated and discussed.

Chapter 5 concludes the findings of the research. This chapter also provides suggestions for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The invention of Self- Compacting Concrete (SCC) as new breed of concrete in the concrete industry had first taken place in Japan in between middle to the late of 1980's (Ouchi et al., 2003). The reason for this first innovation was to improve the quality of properties in concrete which at the same time to overcome problem pertaining to the lack of skilled labour to ensure adequate concrete compaction in structural members having congested reinforcement with complex formwork that requires the greatest external compaction effort. Thus, it leads to the production of advanced concrete, which is known as SCC that provides many benefits to the concrete industry.

SCC is a highly flowable concrete that is dissimilar compared to normally vibrated concrete (NVC) which is very useful to be used in very complex design structure that had many reinforcement obstruction. SCC can be compacted under its own weight without any helps from vibrator or external force. It owns unique properties that are highly flowable with excellent viscosity, non-segregating concrete that can spread even in a very small area and complex structure, as well as maintaining its homogeneity even in the presence of congested reinforcement had contributed for many advantages and can be applied widely in this modern days with rapid development in construction. The application of SCC not only helps to reduce the construction duration but also offers superior quality and durability of concrete as it leads to faster placement with shorter finishing time as well as lesser noise level on construction site and thus improved the productivity in construction.

Nevertheless, SCC is well known as highly flowable concrete, and it requires higher amount of powder content and admixture especially superplasticizer compared to NVC and thus, it leads to increasing amount of material cost (The Concrete Society and BRE, 2005). Based on previous studies, in most recorded cases, the cost of SCC is between 20% to 60% higher compared to similar grade of NVC (Miao, 2009; Nehdi et al., 2004; Ozawa, 2001). Nonetheless, all those problems can be solved by introducing SCC that incorporates mineral admixtures which are currently being abundant as waste product without any recycle or reuse process that had been conducted and costly to dispose (St.John, 1998). This idea gives an opportunity and possibilities for utilization of Palm Oil Fuel Ash (POFA) as supplementary binder in SCC instead of being a waste material only that may contribute towards environmental problems due to large quantities of waste requiring disposal.

For additional information, Malaysia is the second largest producer of palm oil after Indonesia as it produces 17.7 million tonnes of palm oil on 4,500,00 hectares of land in 2008. Furthermore, palm oil production in Malaysia has increased over the years as it reached 16.9 million tonnes in 2010 and 18.9 million tonnes in 2011 (MPOB, 2011). Nevertheless, the increasing in production of palm oil contributes negatively towards volume of wastes in landfills due to uncontrolled economic development and thus causing greater environmental problem. POFA is categorized as one of agro-waste ash from palm oil waste such as palm fibers, kernel shells and empty fruit bunches which were burned at temperature of 800-1000°C in palm mill boilers (Awal and Hussin, 1997). According to Mannan et al., (2004), the plantation of palm oil in Malaysia covered about 2.6 million hectares of the total area with potential for production of POFA were over 3.13 million tonnes annually. As a

result, the abundant amount of POFA can be solved by utilizing it as a mineral admixture by partially replacing cement in concrete, which at the same time can reduce the cost of concrete from the reduced cement usage. From previous research, POFA can be used as mineral admixture in concrete as it contains large amount of silica and thus can be accepted as a pozzolanic material in concrete (Tangchirapat et al., 2009).

The utilization of POFA as a pozzolanic material to partially replace Portland cement has not been investigated extensively especially in SCC. On the contrary, other agro waste ashes as partial cement replacement in concrete had been investigated widely by previous researchers such as sawdust ash (Udoeyo and Dashibil, 2002), rice husk ash (Mehta, 1977), bagasse ash (Singh et al., 2000) just to list a few. From their studies, it has been proven that those agro waste ashes contained a high amount of silica in amorphous form that promotes pozzolanic properties and thus, suitable to be used as supplementary binder in concrete. The studies on POFA were recently investigated and finally, POFA had been acknowledged as material that possesses pozzolanic properties and has an ability to be used as supplementary binder for replacing cement up to 35% in mortar mix that exhibited comparable strength as control mortar (Abu, 1990). This was followed by studies from Awal and Hussin (1996) who reported that the incorporation of POFA in concrete contributed for maximum strength as 30% of replacement by POFA was the optimum results achieved in concrete as for further increment in percentage of POFA content would lead for reduction in strength concrete.

On the contrary, the recent studies by Chandara et al. (2010) and Megat Johari et al. (2012), the new discovery regarding to POFA was found which the higher strength of concrete was given by highest replacement of POFA that was at

60% as the fineness of POFA was increased to be a very fine particles around 2 μ m. Furthermore, they also discovered new method in processing POFA such as via sieving, grinding and burning in order to achieve higher effectiveness and improved reactivity. Thus, based on these studies, it is proven that the increasing in fineness of POFA would lead to excellent development of strength in concrete compared with coarser POFA which still contains significant unburned carbon inside it. As a result, based from those previous studies, it can be concluded that POFA is a natural material that possesses pozzolanic properties as in accordance with ASTM C618-05 (2005) which satisfied to be used as supplementary binder in concrete.

For the past century, many researchers (Mehta, 1983; Tay and Cheong, 1991; Neville, 1996) had carried out the studies on the influence of pozzolanic material on the properties of normally vibrated concrete (NVC). For this case of study, an effort had been made for evaluating the effectiveness of POFA as supplementary binder for manufacturing SCC. The SCC unique performance in fresh properties had been determined in term of its filling ability, passing ability and resistance to segregation characteristics as well as setting times. On the other hand, the effects of POFA on hardened properties of SCC in terms of compressive strength; porosity and water absorption; initial surface absorption (ISAT); gas permeability and water permeability; rapid chloride permeability (RCPT) and rapid chloride migration (RCMT) tests had been investigated. From there, it is believed that the inclusion of POFA as pozzolanic material in producing SCC not only can improve its development in strength and durability properties but also lead to decrease the cement usage. Consequently, it could reduce the cost of construction as well improve the environmental aspect as the amount of waste to be disposed in landfills can manage to be controlled. In addition, the inclusion of POFA as a supplementary

binder in SCC could encourage other researchers to further explore on utilizing other by-product mineral admixtures that could significantly promote environmental friendliness as well can manage to balance the ecosystem.

2.2 Self-Compacting Concrete (SCC)

Self-Compacting Concrete (SCC) is one of the special types of concrete considered in advanced concrete technology. Professor Hajime Okamura (1986) was the first introducing the idea of designing SCC but later in 1989, the SCC's model was developed by Professor Ozawa. As mentioned earlier, SCC was first developed due to reduction in number of skilled labor, which affects the quality of construction. Therefore, by introducing SCC, the major issue was solved as it improves and produces an excellent durability in concrete structure. According to Dehn et al. (2000), around 1983 era in Japan, the poor performance of concrete structure had become a major factor due to uneven and incomplete compaction, which led to the development of modern SCC aimed towards achieving better quality and performance.

SCC is designated as such, as it requires no helps from any external force; full compaction is achieved under its own weight whereby the SCC should be able to flow freely into every corner of a formwork even in areas with congested reinforcement and inaccessible areas without segregation, while at the same time maintaining its homogeneity. Due to the eradication of compaction, the greatest reduction in porous transition zones between paste and aggregate occurred as the inner segregation between solid particles and liquid is prevented (RILEM TC 174 SCC, 2000). Moreover, the final finishing of SCC produced for a smooth and dense surface level. The idea for better understanding in the development of SCC proposed

by Ozawa et al. (1990) consists of the primary study on workability of concrete (Bartos, 2000). To simplify, the period for the development of SCC, it is explained in Figure 2.1 below.

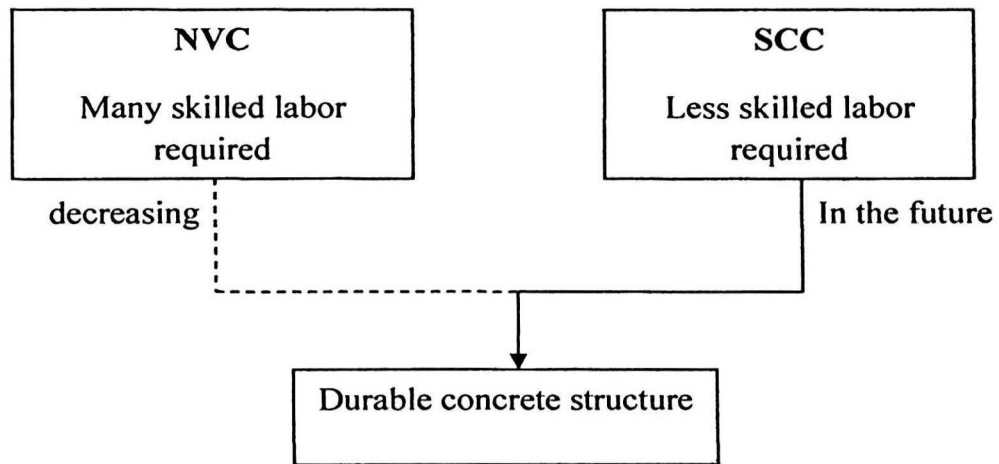


Figure 2.1: Necessity of SCC

(Ouchi and Hibino, 2000)

The compositions of SCC encompass the same constituents as NVC, i.e. consisting of basic materials for producing concrete which are cement, sand, coarse aggregate and water as well as admixtures either chemical admixture or mineral admixture to enhance its performance and quality. Nonetheless, there were some limitations in choosing SCC material in relation to size of aggregates, fineness of sand, water/binder ratio just to list a few as SCC mix is much more sensitive to mixture variations compared to NVC. In the case of NVC, a variation can be managed by applying an external force for compaction work, but for SCC the compaction work is impossible to be done. Therefore, all component materials in SCC must be ensured suitable in order to produce SCC with a greater performance. The comparison of mix design between NVC and SCC is illustrated in Figure 2.2.

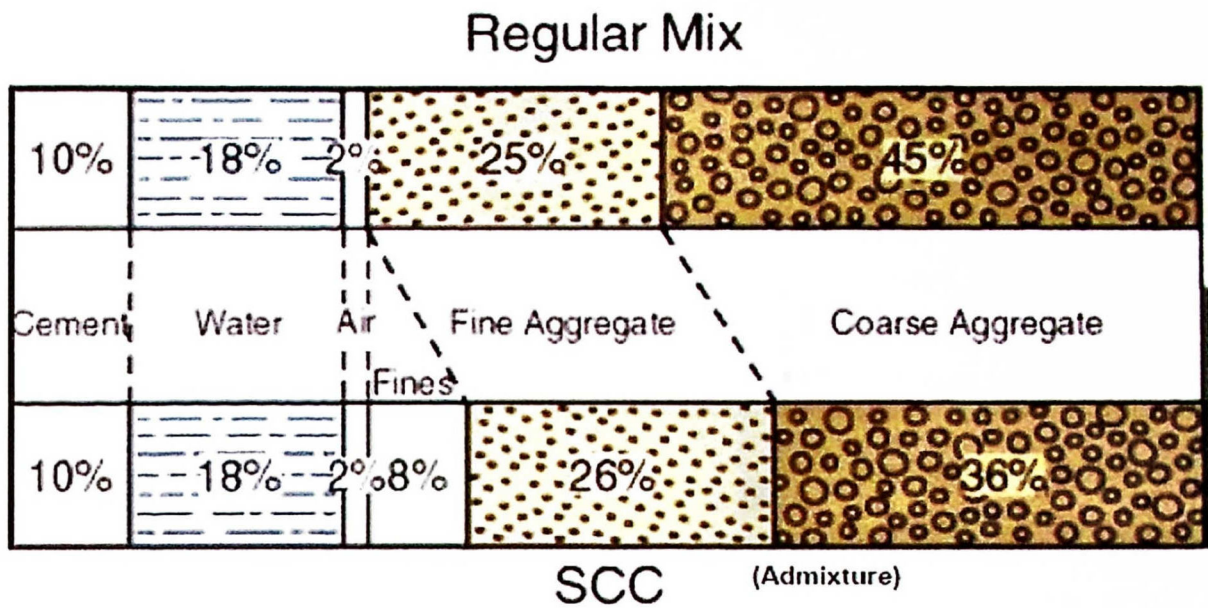


Figure 2.2 Comparison of Mix Proportioning between Normal Concrete and SCC

(Okamura and Ouchi, 2003)

For additional information, SCC can be categorized into three main types which are Powder-types, V-MA type and Combination-type of SCC as it depends on which method to be used for manufacturing the highest viscosity and greatest performance of SCC (Dehn et al., 2000; Holshemacher and Klug, 2000; Nawa et al., 1998; Miao, 2009). Powder-type was the first prototype of SCC developed. It is typified by high powder content with low water/powder ratio that necessitated to restrict the free water content as well as maximized the plastic viscosity. The main source of this type of SCC is the powder content as increasing in powder content lead to a desired design mix which at the same time reducing the value of water/powder ratio as well as being supported by superplasticizer in order to achieve a greater consistency and workability performance. Nonetheless, precaution steps need to be ensured when making a modification in component of concrete as this type of mix is

very sensitive due to high powder content. Typically, mineral admixture is used as supplementary binder in concrete to replace cement in order to offer for excellent strength performance and controlled heat of hydration. The concentration should be taken while dealing with superplasticizer and powder together as it might affect the results if too much or less of those materials being added (Miao, 2009).

On the other hand, the second type of SCC is VMA-type mix. This type of mix is based on a high viscosity modifying agent (VMA) dosage. VMA can be defined as an admixture that controls the cohesion of SCC without changing its fluidity as well as to lessen the consequences of variations such as moisture content, fineness of the sand in order to produce more robust SCC and reduce its sensitivity to a small variation in concrete materials. In this type of mix, VMA is added firstly to enhance its plastic viscosity. It contains higher superplasticizer dosage or water/powder ratio compared to powder-type SCC in order to achieve the desired filling ability properties as it is controlled by the addition of VMA. Nevertheless, attention should be given to the compatibility between superplasticizer and VMAs for a successful SCC mix design. The last one is the combined-type of SCC which is a combination of powder-type of SCC with the addition of a small amount of VMA in order to enhance the robustness of the concrete. Lower VMA content is added compared to powder-type SCC. These types of mix produce high viscosity concrete offered by VMA together with powder. From previous studies by Miao (2009), this combined-type of SCC contributed towards higher filling ability, higher segregation resistance as well as development of a greater robustness. Nonetheless, consideration should be given on the compatibility between superplasticizer, powders and VMAs in order for them to mix well. In the case of the present studies, the powder-type SCC had been chosen as a design mix without the use of VMA.

From theoretical point of view, the mix design of SCC is responsible to ensure achievement of the relevant characteristics of the fresh SCC characteristics, while having not much different in hardened concrete characteristics in comparison to NVC. Nonetheless, the different between these two mixes is only consistency as SCC required much higher consistency and viscosity for flowable concrete. The characteristics of SCC can be seen clearly through its unique properties in the fresh state. The design mix of SCC focuses on its ability to flow under its own weight without compaction and segregation while maintaining its homogeneity even though through heavily congested reinforcement (Ouchi et al., 2003). SCC has three main properties in its fresh state namely filling ability, passing ability and resistance to segregation, as the concrete can only be classified as SCC when these three requirements are fulfilled (European Guidelines for SCC, 2005; The Concrete Society and BRE, 2005). The term filling ability can be defined as the ability of SCC to flow freely and completely filled all the spaces in the formwork under its own weight without any external compaction. For the case of passing ability, it can be defined as the ability of fresh SCC to flow through and around obstacles such as complex reinforcement set-up and restricted spaces without blocking and segregation. As for segregation resistance, it can be defined as the ability of SCC to maintain its homogeneity in composition during and after transporting and placing. The characteristic of SCC which is filling ability, has usually been used as primary check for fresh SCC in order to determine whether the consistency meets with the specification (European Guidelines for SCC, 2005). On the other hand, for higher consistency of concrete, passing ability had been used to verify compliance with the requirements (Domone, 2000).

Furthermore, SCC provides many benefits to the concrete construction industry. SCC could be developed for greater qualities as well as improving productivity and working condition (De Schutter et al., 2008; The Concrete Society and BRE, 2005). SCC offers a greater strength and improves the durability of concrete as well as provides for a good finishes after placing with a smooth and dense surface. The idea of increasing reinforcement volume; via the use of smaller bar diameter for preventing crack; as well as using complex formwork provided greater difficulty for compaction and thus, SCC is beneficial and it improves the structural performances (Okamura and Ouchi, 2003b; RILEM TC 174 SCC, 2000). Therefore, SCC meets the entire requirement above for providing homogeneous concrete even in heavily congested reinforcement and at the same time increasing the productivity on construction site through shorter construction period, which could reduce the labour cost. Besides, SCC also offers a comfortable working environment as it reduces the noise pollution by eliminating problems associated with vibration. Thus, it solves the health problem associated with the use of vibration equipment that could cause deafness upon prolonged exposure (RILEM TC 174 SCC, 2000). As a result, SCC is well known as a new invention of concrete as it provides for a 'quite' transformation in construction (The Concrete Society and BRE, 2005). Hence, because of the greater development in SCC, it had been used widely in pre-cast and pre-stressed concrete industry as well as in cast-in-place construction (Ouchi et. al., 2003).

In addition, according to Professor Aitcin, concrete with high durability owing to low water/cement ratio could be described as High Performance Concrete (Ouchi et al., 1996). Therefore, the phrase of "high performance concrete" was later on used widely which related to high durability concrete. Ever since then, the term of

'Self-Compacting High Performance Concrete' had been introduced by Okamura (1997). As a result, nowadays SCC is being applied almost worldwide. Many researchers have shown their interest as SCC is being studied around the world and is being applied to overcome many problems associated with NVC. Nevertheless, there is little information regarding standard method of the assessment of the characteristics of SCC. In addition, this present study will provide some valuable information and insight pertaining to the influence of POFA on SCC properties which can encourage other researchers to continuously find new development and findings on SCC in the near future.

2.3. Pozzolan and Pozzolanic Cements

2.3.1. Definition and Classification

The term of "Pozzolan" was first introduced by an Italian in order to describe the volcanic ash mined at Pozzuoli, a village close to Naples. Meanwhile, around 1500 B.C. the word pozzolan was being invented or conveyed as a similar natural ash that produced from volcanic explosion in Santorini Island, which had been utilized to produce lime-pozzolan in Greece (Chandara, 2011). Based on ASTM C618-05 (2005), pozzolan can be defined as siliceous or siliceous and aluminous material which in itself possesses little or no cementitious properties but which will in finely divided form and in the presence of water will chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Pozzolanic material can be natural in origin or artificial which can be simplified either as natural materials or by-product materials.

According to Malhotra and Mehta (2004), pozzolans or pozzolanic material are usually verified as mineral admixture in production of blended cement. Mineral