OPTIMUM MIX DESIGN OF SELF-COMPACTING CONCRETE BY USING PULVERIZED FLY ASH AND RICE HUSK ASH AS CEMENT REPLACEMENT MATERIALS

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Optimum Mix Design for Self-Compacting Concrete (SCC) by using Pulverized Fly Ash (PFA) Rice Husk Ash (RHA) as Cement Replacement Materials

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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SITI AMINAH BINTI ABBAS

ABSTRACT

This report basically discusses about the research done and basic understanding on the chosen topic, which is **Optimum Mix Design for Self-Compacting Concrete (SCC) by using Pulverized Fly Ash (PFA) and Rice Husk Ash (RHA) as cement replacement material**. The objective of the project was to find the optimum mix design SCC incorporating with PFA and RHA and other characteristics of SCC containing PFA and RHA as the cement replacement material. The challenge in this project was to find the most favorable mix design that will resulted in high strength concrete with high workability rate. Lab testing was done for the designed mix for fresh properties of concrete as well as the hardened concrete. The fresh concrete was tested for its workability, viscosity and resistance to segregation. Once the concrete has hardened it was tested for compressive strength, porosity, permeability and chloride migration.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDIES

Self-Compacting Concrete (SCC), also known as Self-Consolidating Concrete or High Performance concrete was developed in Japan during the late 1980s. The development of SCC started when the need of more durable concrete arises, and since durability of concrete directly connected to the adequate compaction after placing the concrete, a concrete that can move into every corner of the formwork on its own weight is the ideal solution [1,2].

To make durable concrete structures, sufficient compaction by skilled workers is required. However, the gradual reduction in the number of skilled workers in Japan's construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structures independent of the quality of construction work is the employment of self-compacting concrete, which can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction. This self compacting concrete has since been used in major constructions throughout Japan and is gaining its popularity in the European country.

SCC offers many advantages for the precast, prestressed concrete industry and for the cast-in-place construction:

- Low noise-level in the plants and construction sites
- Eliminated problem associated with vibration
- Less labor involved and faster construction
- Improved quality and durability
- Higher strength

1.2 PROBLEM STATEMENTS

One of the disadvantages of Self Compacting Concrete (SCC) is its cost, associated with the use of chemical admixtures and use of high volume of Ordinary Portland Cement (OPC). One alternative to reduce the cost of SCC is the use of mineral additives such as Pulverized Fly Ash (PFA) and Rice Husk Ash (RHA), which is a fine material added into concrete. As the mineral additive replaces part of the Portland cement, the cost of SCC could be reduced especially if the mineral additive is an industrial by-product or waste.

It is also known that PFA and RHA generally increase the workability, durability and long term properties of concrete. Therefore, the use of this type of mineral additive in SCC will make it feasible, not only to decrease the cost of SCC but also to increase its long term performance. In general, concrete made with OPC containing both PFA and RHA has a higher compressive strength than concrete made with Portland cement containing either PFA or RHA on their owns.

As the knowledge of SCC is widely spread, not much of its characteristics and properties are known. SCC is widely used in pre-stressed concrete, prefabricated sections and in major structures such as bridges. It has become a major concern of corrosion in the structure using SCC since they are exposed to harsh environment. This research will focus on the durability and corrosion characteristics of self compacting concrete.

1.3 OBJECTIVES & SCOPE OF STUDY

The main objectives of this project are:

- To establish the optimum mix design and the rheological properties of Self-Compacting Concrete (SCC) by using Pulverized Fly Ash (PFA) and Rice Hush Ash (RHA) as cement replacement materials.
- To determine the compressive strength, porosity and chloride migration of the design mix at 1, 3, 7 and 28 days.

The scope of work for the rheological properties conducted for fresh concrete, and the test conducted to investigate its flow ability and workability. Once the concrete hardened, it tested for compressive strength, porosity and chloride migration. The mix design generally based on the approach to evaluate the water demand, determine the proportion of aggregate, dose of admixture to give the required robustness and test the properties of the SCC in the fresh and hardened state.

CHAPTER 2
LITERATURE REVIEW

2.1 SELF COMPACTING CONCRETE

Self Compacting Concrete (SCC) is concrete that can flow alone under its dead weight up to leveling; air outs and consolidates itself without additional compaction. SCC mixes can be designed and placed successfully for concrete with normal and congested reinforcement. The three key fresh properties of SCC are:

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

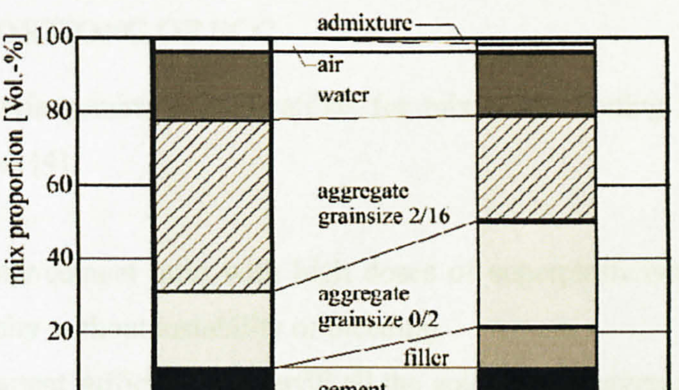

Figure 1: Mix composition of SCC in comparison with normal vibrated concrete [3]

The basic ingredients in SCC mixes are practically the same as those used in conventional concrete. The differences are that it has additions of filler material such as Pulverized Fly Ash (PFA), limestone powder, ground granulated blast-furnace slag (GGBS), silica fume, quartzite powder and rice husk ash (RHA) [3]. A comparison of a typical mix design of SCC and conventional concrete is shown in **Figure 1**.

As a rule of thumb for normal concrete, the more it is compacted, the greater its strength and durability. Concrete must be fully or well compacted in order to be impervious to water and provide adequate protection against corrosion of the reinforcement.

The development of SCC has led to substantial improvements in the environment and working conditions; there is less energy consumption, less vibration, greater productivity, less noise, and decreased absence of workers due to sickness.

The development of SCC technology is having positive impact beyond its own boundaries. As for SCC, the absence of compaction does pose a major concern. For conventional concrete, due to its worldwide application and extensive usage, much of its characteristics are well known. The need and desire for SCC, much of it characteristics is still unknown as researches is still in progress worldwide.

2.2 MIX PROPORTIONG OF SCC

The essential criteria general considerations for mix proportioning for achieving the three key properties [4]:

- A low water/cement ratio with high doses of superplasticiser to achieve high flow capacity without instability or bleeding
- A paste content sufficient to overfill all the voids in the aggregate skeleton to the extent that each particle is surrounded by an adequate lubricating layer of paste, thus reducing the frequency of contact and collision between the aggregate particle during flow

- A sufficiently low coarse aggregate content to avoid particle bridging and hence blocking flow when the concrete passes through confined spaces.

The general approach is to select the most consistent and best-graded and shaped aggregate economically possible, and to use high paste fractions to increase space between the aggregate particles. The rheology is controlled by adjusting the water-to-powder ratio and using appropriate admixtures specifically designed for SCC production.

Highly gap graded aggregates mixtures should be avoided as the SCC mix will have a tendency to bleed or segregate, and will increase the overall paste fraction requirement of the concrete.

2.3 FUNCTION OF PULVERIZED FLY ASH AND RICE HUSK ASH

Pulverized Fly Ash (PFA) and Rice Husk Ash (RHA) are materials containing reactive silica which on their own have little or no binding property but, when mixed with lime in the presence of water, will set and harden like cement. PFA and RHA is an important ingredient in the production of cement replacement material to Ordinary Portland Cement (OPC).

Cement replacement material provide an excellent technical option to OPC at a much lower cost and have the potential to make a significant contribution towards the provision of low cost building materials and consequently affordable shelter.

An important difference between cement and PFA with RHA is the much lower content of CaO in PFA and RHA, which means that they have pozzolanic instead of hydraulic properties. A pozzolan mainly consists of SiO_2, or of SiO_2 and Al_2O_3 which in presence of water will react with $Ca(OH)_2$ to form compounds which have cementitious properties.

This principle is demonstrated in the following reactions:

Portland cement: $C_3S + H_2O \rightarrow CSH + CH$ (rapid reaction)

Pozzolan : pozzolan + $CH + H_2O \rightarrow CSH$ (slow reaction)

The alkalinity of the pore fluid does not change much because of the chemical binding of the CH.

In general the advantages can include:

- control of strength , particularly where the high strength which would occur with the use of Ordinary Portland Cement (OPC) alone is not required
- reduced heat of hydration and therefore reduced risk of cracking from thermal strains
- improved stability and rheological behavior
- extended consistence retention
- minimize the environmental pollution

2.4 AGGREGATES

Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Although some variation in aggregate properties is expected, characteristics that are considered when selecting aggregate include; grading, durability, particle shape and surface texture, abrasion and skid resistance, unit weight and voids, absorption and surface moisture.

It might be expected that rounded, uncrushed coarse aggregates from, for example, gravel deposits, and would be preferable to angular crushed rock aggregates for achieving the high flow properties of Self Compacting Concrete (SCC). However, these are not readily available in many locations, and crushed rock aggregates are commonly used.

Most applications of SCC have used a maximum aggregate of 16mm and 20mm. depending on local availability and practice. There is no evidence of a pattern of variation of pattern of variation of powder content with aggregate size – indicating that the aggregate grading is probably a more important factor in mix design. As with coarse aggregate, fine aggregates conforming to local standards and practice have generally been found to be suitable for SCC. Of particular amount of very fine material

For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, which account for 60 to 75 percent of the total volume of concrete, are divided into two distinct categories; fine and coarse. SCC requires higher amount of fine aggregates compare to coarse aggregates. Highly gap graded aggregate mixtures should be avoided as the SCC mixtures will have a tendency to bleed or segregate.

2.5 SUPERPLASTICIZERS

The increasingly widespread availability of superplasticizers in the 1970s led initially to the introduction and use of flowing concrete, which had significant advantages in many production situations [5]. The development of SCC can be seen as a logical step in exploitation of superplasticisers technology. A distinctive advantage is the flexibility of their chemical structure which can be synthesized or modified so that their properties can be tailored to overcome compatibility issues and to meet the varying needs of SCC for different application. Although successful, these materials often experienced compatibility problems with cements such as workability retention.

They achieve dispersion in two ways. First, they attach themselves to the cement particles and impart a negative surface charge thus causing electrostatic repulsion and deflocculation, thus releasing water to increase mobility. In addition, the backbones of their molecules have side chains of a varying length which physically keep the cement particles apart thus allowing water to surround more of their surface area, a mechanism known as steric hindrance [6].

Superplasticizers are also often used when pozzolanic ash is added to concrete to improve the strength. The method of proportioning is especially popular when producing high strength concrete and fiber reinforced concrete. Adding 2% superplasticizer per unit weight of cement is usually sufficient. However, most commercially available superplasticizers come dissolved in water, so extra water has to be accounted for in mix proportioning. Adding excessive amount of superplasticizers will result in excessive segregation of concrete and not advisable. Some studies also show that too much superplasticizers will result in a retarding effect.

2.6 DURABILITY

In the recent years, the concrete mixture design emphasized not only compressive strength, but also durability of concrete. Once a concrete is cracked or becomes porous, then it is liable to be attacked by surrounding deleterious substance, and will induce durability problem and reduce service quality. The probability of forming concrete crack and pore is closely related to the amount of mixing water and curing quality.

Premature deterioration of concrete structures has created awareness and concern about the durability of concrete. Concrete mixtures in the construction of residential basement walls and foundations have high water to cement (w/c) ratio (w/c > 0.6) and low cement content (<280 kg/m^3). The result is friable concrete with a highly porous surface layer and high potential for cracking. The defects have a direct impact on the durability of concrete.

The external detrimental elements or deleterious substances are sulfate ion, seawater, acid rain, the variation in temperature and humidity, and strong sunshine, while the internal deleterious substances of concrete are those contained in the concrete ingredients such as sodium chloride. The substances cause concrete cracks and increase pores, and are closely related to water content and cement content of concrete. Therefore, the important strategies for maintaining durability of concrete are to limit the amount of mixing water and reduce the amount of cement.

2.7 CORROSION

Many existing concrete structures show significant corrosion, often when comparatively new, leading to the need for expensive repair. In most cases either the structures were not durable enough or the appropriate maintenance had been neglected. Corrosion of the reinforcement embedded in concrete causes most of the failures of concrete structures. Since then chloride induced corrosion has become much more important for structures exposed to chloride-containing environments.

The high alkalinity of the concrete pore (pH over 12.5) leads to a passive layer forming on the steel that reduces the corrosion attack to negligible values. As long as this passive layer is sustained, corrosion not occurs. Two process may destroy this protection layer by carbonation of the concrete and chloride attack.

As discussed earlier, SCC is mainly used for reinforced concrete constructions where the formwork is densely crowded by steel reinforcements and also for pre- cast element which is mainly used for bridge structures. Bridges as compared with other structures is the most exposed structure to the environment which might lead to corrosion to the steel reinforcement.

As we all know, for steel to corrode (rust), it needs the presence of air and water. However, in a dense concrete a steel bar is less likely to corrode although there are presence of moisture and air (due to porosity).

It is well known that concrete is very well porous and contains moisture and somehow the moisture content would very much fluctuate according to the environment or usage of the concrete structure. But, steel corrosion does not normally occur in normal conditions. This is because concrete is alkaline, the opposites of acidity. Metal corrodes in acids; therefore they are protected from corrosions by alkalis.

The alkaline condition leads to a 'passive' layer forming on the steel surface. The layer is a dense, impenetrable film which with properly mixed concrete and maintenance prevents further corrosion on the steel. The layer formed on steel in concrete is probably part metal oxide/ hydroxide and part mineral from the cement. A true passive layer is a very dense thin layer of oxide that leads to a very slow rate of oxidation (corrosion). That is why, when the steel corrodes, we can see rusts formed on its surface. In a concrete structure, this formation of rusts could incur internal stress which might damage the structure in aesthetically and even its integrity.

Once the said passive layer breaks down then areas of rust will start appearing on the steel surface. The chemical reactions are the same whether corrosion occurs by chloride attack or carbonation. When steel in concrete corrodes, it dissolves in the pore water and gives up electrons.

The two electrons (2e-) created in the anodic reaction must be consumed elsewhere on the steel surface to preserve electrical neutrality. Thus, it is not possible for large amounts of electrical charge to build up at one place on the steel. Another chemical reaction must occur to consume the electrons. This reaction consumes water and oxygen.

However, notice that this reaction produces hydroxyl ions (2OH-). These ions increase the local alkalinity and therefore strengthen the passive layer. Also, note that water and oxygen are needed at the cathode for corrosion to occur. Both these reactions are only the first steps in the process of creating rust. Several more stages must occur for 'rust' to form. This can be expressed in several ways:

The anodic reaction : $Fe \rightarrow Fe^{2+} + 2e^-$

The cathodic reaction : $2e^- + H_2O + \frac{1}{2} O_2 \rightarrow 2OH^-$

$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$ [Ferrous hydroxide]

$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3$ [Ferric hydroxide]

The full corrosion process is illustrated in Figure 2.0. Unhydrated ferric oxide (Fe_2O_3) has a volume of about twice that of steel it replaces when fully dense. When it becomes hydrated it swells even more and becomes porous. Thus, volume increase at the steel and concrete interface is two to ten times.

The drastic increase leads to cracking and spalling as the usual consequence of corrosion of steel in concrete and the red/brown brittle, flaky rust on the bar and the rust stains seen at cracks in the concrete.

The fastest ingress of chloride into concrete is caused by capillary suction of chloride containing water; sea water which results in more or less deep chloride profiles. Wetting and drying of the concrete accelerates the chloride ingress. The chloride has fourfold negative effect in reinforced concrete (Hunkeler 1994):

- it destroys the passive film of the steel rebar and makes corrosion attack possible
- it reduces the pH of the pore water since it reduces the solubility of $Ca(OH)_2$
- it increases the moisture content because of hygroscopic properties of salt present in concrete.
- it increases the electrical conductivity of the concrete.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 PRELIMINARY PROJECT WORK

3.1.1 Literature review

Literature review was conducted to expose to the previous studies that has been done on the topic of the project. Literature review is a research based on the journals, publications and also reference books from the library. The idea on how to conduct the project was planned from the knowledge gained from the literature review. Also, the objectives and scope of study is determined in this stage. After data and information gathered, literature review was done focusing on SCC and durability in concrete.

3.1.2 Discussions

In addition, meeting with the supervisor, Assoc. Prof. Dr. Nasir Shafiq and Mr. Agus Kurniawan were conducted to ensure that the project is going on the right path. The meetings lead to a better understanding besides in depth researches.

3.1.3 Mix Design

Then, the design mix was determined. The design mix is taken from previous studies and projects that have been done. 5 mixes were made consisting of conventional mix which acts as the control mix, PFA and RHA #1, PFA and RHA #2, PFA and RHA#3, RHA and PFA #4. Each mix has 10 % filler content from the total binder and 2-3 % admixture content (superplasticisers) with the exception of the control mix. The variables are the water/ cement ratio (w/c) and the water/ binder ratio (w/b).

These design mix is selected after review of many articles and journals on Self-Compacting Concrete and the use of cement replacement materials such as Rice Husk Ash (RHA) and Pulverized Fly Ash (PFA).

Table 1: Amount of material

NAME	Mix No	OPC	PFA	RHA	CA (20-8)	CA (8-4)	FA	W/B	w/c	water	S/P (%)	S/P weight	total
SCC	1	400	50	50	312	605	833	0.30	0.38	150	2	10	2400
	2	400	50	50	312	605	833	0.30	0.38	150	3	15	2400
	3	400	50	50	310	600	820	0.34	0.43	170	2	10	2400
	4	400	50	50	310	600	820	0.34	0.43	170	3	15	2400
Control	nor mal	500			265	575	810	0.4		250	0	0	2400

Table 2: Trial mixes for different aggregate proportion of $0.0243m^3$

NAME	Mix No	OPC	PFA	RHA	CA (20-8)	CA (8-4)	FA	water	SP	total
SCC	1	9.72	1.215	1.215	7.5816	14.7015	20.2419	3.645	0.243	58.3
	2	9.72	1.215	1.215	7.5816	14.7015	20.2419	3.645	0.3645	58.3
	3	9.72	1.215	1.215	7.533	14.58	19.926	4.131	0.243	58.3
	4	9.72	1.215	1.215	7.533	14.58	19.926	4.131	0.3645	58.3
Control	normal	12.15			6.4395	13.9725	19.683	6.075	0	58.3
total mix	sum	51.03	4.86	4.86	36.6687	72.5355	100.0188	21.627	1.215	

3.2 MATERIAL PREPARATIONS

Before doing the mixing, preparation of the aggregates is very important and must be done days before the mix to avoid error during the mix.

3.2.1 Portland Cement

SCC requires a high cement content and low water/cement ratio. Cement is a powder, which by hydraulic reaction (i.e. with water) forms a solid, cohesive mass. Ordinary Portland Cement (OPC), which is the standard, grey cement used for most purposes. Ordinary Portland cement sets by hydraulic (i.e. water) reaction. It is a complex mixture of components, probably the most important of which are dicalcium and tricalcium silicates (C_2S and C_3S to cement chemists). Besides that it also contains tricalcium silicate and tetracalcium aluminoferrite. The water/cement ratio is of paramount importance to the final set strength of the concrete, and the cement/aggregate ratio and aggregate size distribution are also important.

Figure 2: Ordinary Portland cement

3.2.2 Aggregates

Preparation of aggregates took 2 days as we need to sieve, soak into the water and let it dry for 1 day at room temperature. Sieve analysis need to conduct to ensure all sizes of aggregates are being graded well. Crushed granite with a maximum nominal size of 20 mm was used as the coarse aggregate, and local natural sand was used as the fine aggregate. The aggregates sizes the author sieved vary from 20mm to 8mm, 8mm to 4mm. After conducting sieve analysis, the aggregates need to be soaked into water for 24 hours. The purpose is to remove dirt at surface of aggregate that might disturb strength proportion of concrete and well ensured the aggregated are fully saturated. Then, the aggregates must be dried for a day at room temperature. The purpose is to obtain saturated surface dry aggregate and ensure aggregate will not absorb water during the mix. If the aggregates are too dry, they can absorb the water during the mix and will disturb the flowability of the concrete.

Figure 3: Aggregate 20-8mm

Figure 4: Aggregate 8-4mm

Figure 5: Fine aggregate

3.2.3 Superplasticizers

The necessary ingredients for manufacturing SCC are superplasticisers. Superplasticizers are a chemical admixture that can be added to improve workability. It is always available in the laboratory and can utilize in the concrete mix to produce stronger concrete and less water added.

Figure 6: Superplasticizers in environmental control room

Figure7: Small amount superplasticizers

3.2.4 Preparation of PFA and RHA

RHA will be burn in the controlled incinerator and grind by before used as additive in the mixing. RHA burned so that we can get the ash of it which is free from activated carbon. It will be grind so that we can get the finer RHA. The final process before use the RHA in the mixing is sieving the grinded RHA until it pass through 180µm pan size. while PFA always available in the laboratory.

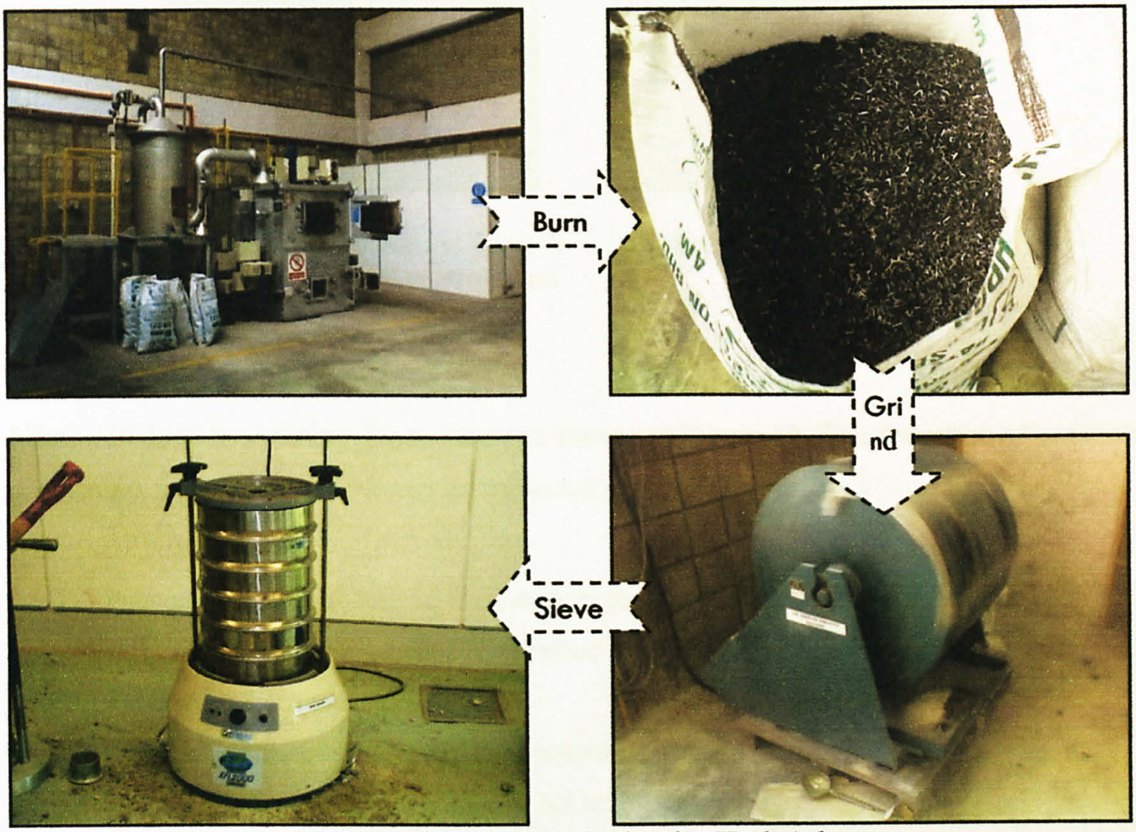

Figure 8: Process to obtain Rice Husk Ash

Figure 9: Rice Husk Ash

Figure 10: Pulverized Fly Ash in environmental control room

Figure 11: Pulverized Fly Ash

3.3 CONCRETE MIXING

Mixing is done by rotating drum mixer as shown in **Figure 12**. The sequence of concrete mix is very important and it must be followed accordingly.

1) Pour all coarse and fine aggregates into the mixer and mix for 25 seconds to ensure uniform distribution between both materials.
2) Pour half of the water and mix for 1 minute.
3) Leave the mixes for 8 minutes to let both coarse and fine aggregates to absorb water.
4) Pour all Portland cement into the mixer and mix for 1 minute.
5) Pour another half of the water and add superplasticizers and mix for 3 minutes.
6) Finally perform hand mixing until the mix is in uniform stage.

Figure 12: Rotating drum mixer

3.4 CONCRETE CASTING

Each mix will have two 150 mm^3 and six 100 mm^3 cubes to be used for determining compressive strength and six 50 mm^3 for chloride migration test. Then, each mix will also have a slab 100 mm^2 x 500 mm which after 28 days will be core into a 1 inch cylinder with 1.5inch diameter.

Table 3 Sample of tests

Test	Size	Item per mix	Days of curing				After 28 Days,			Total sample
			1	3	7	28	24 Hours	72 Hours	7 Days	
Compressive Strength	100 mm^3 and 150 mm^3 cubes	2	√	√	√	√				10
Porosity	100 mm^2 x 500 mm slab	1				√				5
Chloride migration	50 mm^3 cubes	6					√	√	√	30

3.5 CONCRETE CURING

After removal of steel moulds on the second day, the samples will be placed inside the curing tank until the day of testing. The purpose of curing is to avoid shrinkage cracking due to temperature fluctuation and also to gain the maximum strength of the concrete.

Figure 13: Curing

3.6 FRESH CONCRETE TEST

Several methods conducted to evaluate the workability of fresh SCC such as slump flow, V-Funnel and L-Box test. The entire test for fresh concrete is in accordance with The European Guidelines for SCC (2005), which reference standard is European Standard. Tests that were going to be conducted for this project are;

3.6.1 Slump Flow Test

The slump flow test aims at investigating the filling ability of SCC. It measures two parameters: flow spread and flow time T50 (optional).

The basic equipment is the same as for conventional slump test. However, the concrete placed into the mold is not rodded. When the slump cone has been lifted and the sample has collapsed, the diameter of the spread is measured rather than the vertical distance of the collapse. The diameter should be between 600mm to 750mm.

The slump flow is influenced primarily by the yield value of the concrete. The lower the yield value the larger is the extended circle of concrete formed. The yield value depends in turn mainly on the degree of agglomeration of the fine constituents in the concrete, which can be reduced most effectively with super plasticizers. The slump flow is therefore primarily suitable for assessing the yield value of the SCC and the optimum super plasticizer content.

Equipment

- Steel plate
- Slump cone.
- Stopwatch with the accuracy of 0.1 second for recording the flow time T50.
- Measuring scale and guidance

 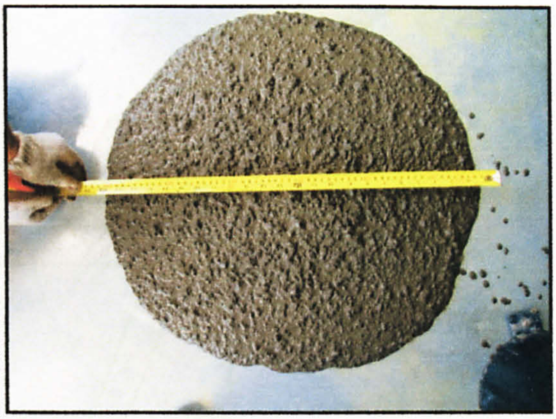

Figure 14: Slump Flow Test

Test procedure

- Place the cleaned base plate in a stable and level position.
- Fill the cone with the sample from the bucket without any external compacting action such as rodding or vibrating.
- Lift the cone perpendicular to the base plate in a single movement, in such a manner that the concrete is allowed to flow out freely without obstruction from the cone, and start the stopwatch the moment the cone looses contact with the base plate.
- Stop the stopwatch when the front of the concrete first touches the circle of diameter 500 mm. The stopwatch reading is recorded as the T50 value. The test is completed when the concrete flow has ceased.
- Measure the largest diameter of the flow spread, *d*max, and the one perpendicular to it, *d*perp, using the ruler (reading to nearest 5 mm). Care should be taken to prevent the ruler from bending.

3.6.2 V-Funnel Test

Proposed for testing viscosity and deformability of concrete. The V-funnel flow time is the period a defined volume of SCC needs to pass a narrow opening and gives an indication of the filling ability of SCC provided that blocking and/or segregation do not take place; the flow time of the V-funnel test is to some degree related to the plastic viscosity.

Equipment

- V-Funnel
- Stopwatch

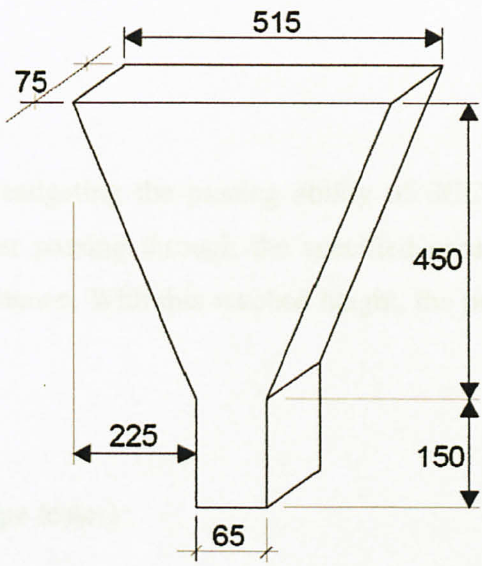

Figure 15: Dimensions of the V-funnel

Test procedure

- Place the cleaned V-funnel vertically on a stable and flat ground, with the top opening horizontally positioned.
- Wet the interior of the funnel with the moist sponge or towel and remove the surplus of water, e.g. through the opening. The inner side of the funnel should be 'just wet'.
- Close the gate and place a bucket under it in order to retain the concrete to be passed.
- Fill the funnel completely with a representative sample of SCC without applying any
- Remove any surplus of concrete from the top of the funnel using the straightedge.
- Open the gate after a waiting period of (10 ± 2) seconds. Start the stopwatch at the same moment the gate opens.

- Look inside the funnel and stop the time at the moment when clear space is visible through the opening of the funnel. The stopwatch reading is recorded as the V-funnel flow time, noted as t_V.

3.6.3 L-Box Test

The method aims at investigating the passing ability of SCC. It measures the reached height of fresh SCC after passing through the specified gaps of steel bars and flowing within a defined flow distance. With this reached height, the passing or blocking behavior of SCC can be estimated.

Apparatus

- An L- box (L- type tester)
- Measuring scale
- Stopwatch

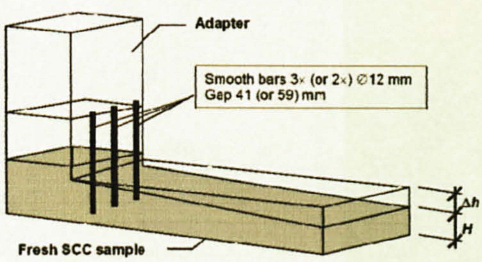

Figure 16: Principle of L-Box test

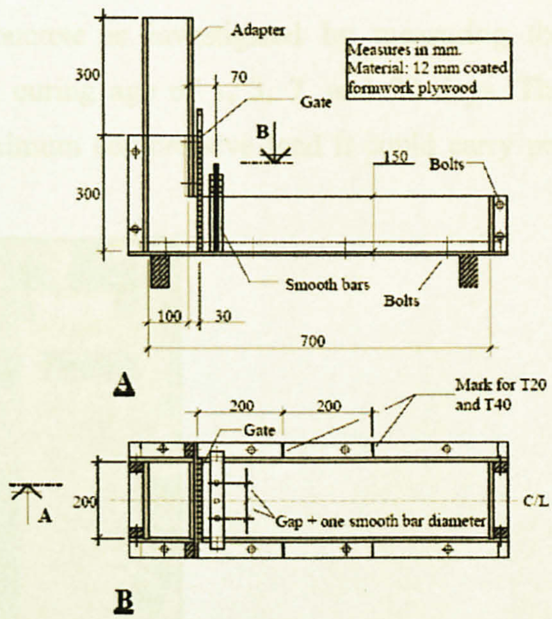

Figure 17: Details dimension of L-box test

Test procedure

- Place the L-box in a stable and level position.
- Attach the sliding gate and pour the sample without applying rodding or vibration.
- When it has reached the desired level, immediately lift the sliding gate and let the concrete flow out of the vertical part into the horizontal part of the L-box.
- Measure the time to reach an arbitrary L – flow with a stopwatch.
- Measure the time from the moment the sliding gate is raised to the moment the tip of concrete reaches the distance of 500 mm.

3.7 HARDENED CONCRETE TEST

Once concrete has hardened it can be subjected to a wide range of tests to prove its ability to perform as planned.

3.7.1 Compressive Strength Test

Comparative performance of hardened concrete is investigated by measuring the development of compressive strength with curing age of 1, 3, 7, and 28 days. The compressive strength was taken as the maximum compressive load it could carry per unit area.

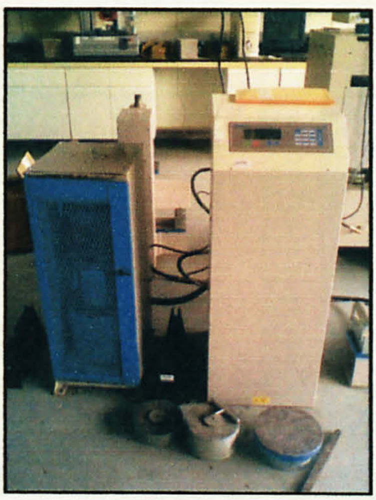

Figure 18: Compression machine (ADR 2000)

3.7.2 Porosity Test

Tests were conducted on a slice of cylinder cores that have been cast into slab (500mm x 100 mm^2). Porosity and permeability concrete is an important factor to classify its durability. Generally concrete of a low porosity will afford better protection to reinforcement within it than concrete of higher porosity. Testing was performed on Helium Porosimeter having a pressure range from sub ambient to 33,000 psi.

The effective core porosity is calculated from;

$$P = \frac{\text{pore volume} \times 100}{\text{bulk volume}}$$

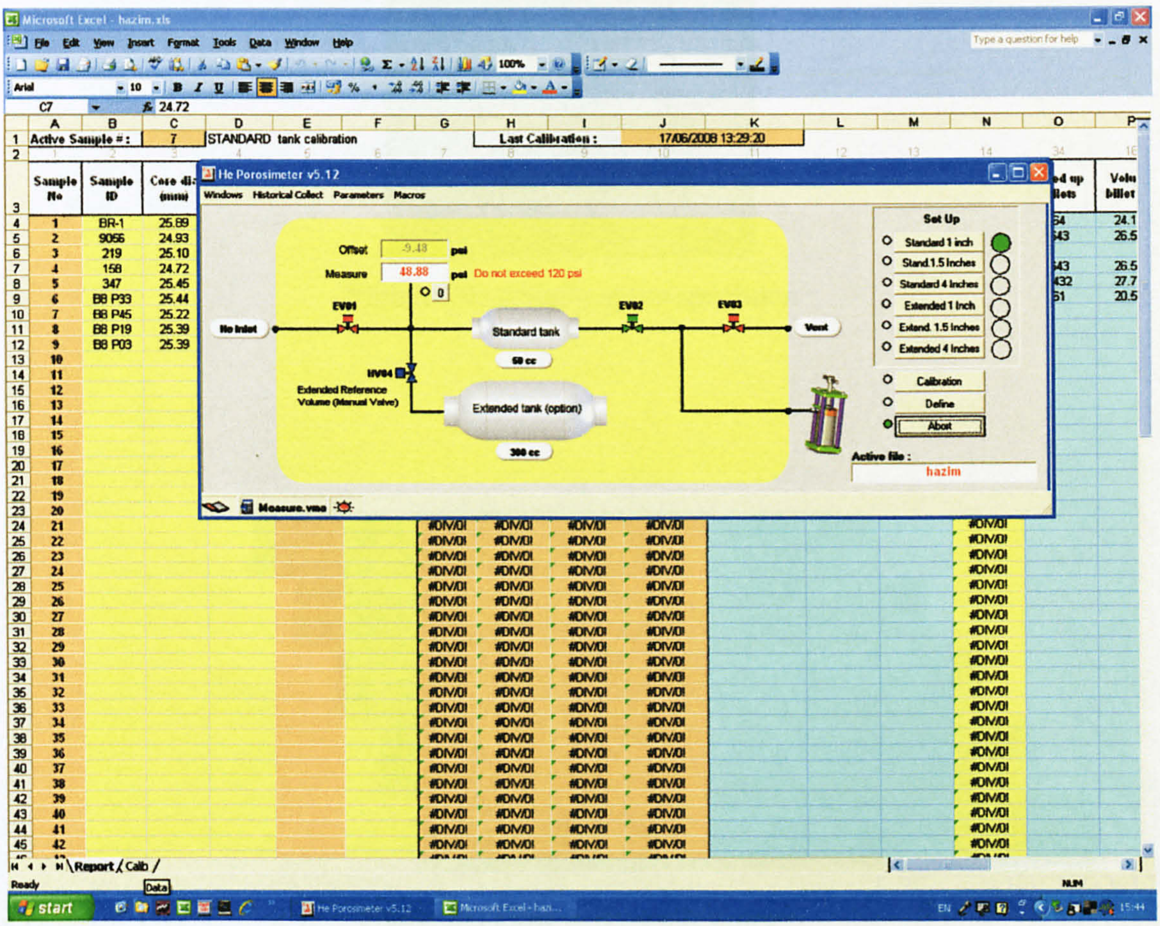

Figure 19: Porosity Test

3.7.3 Chloride Migration Test

At 28days curing, the samples will be cured in water solutions containing 3.0% sodium chloride (NaCl) throughout the experiment. This is to mimic the real environment of structure being exposed to the sea which is prone to corrosion since it is responsible of the salinity of the ocean. Afterwards the specimen is axially split and a silver nitrate solution is sprayed on to the freshly split sections. The chloride penetration depth can then be measured on each section at 10 points from the visible white silver chloride precipitation.

Figure 20: Axially splits specimen

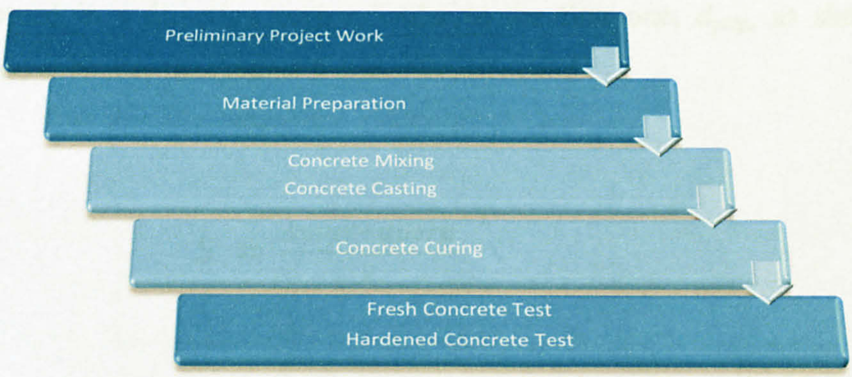

Figure 21: Flow of the methodology

CHAPTER 4
RESULTS AND DISCUSSION

4.1 FRESH CONCRETE TEST

For each mix, the fresh concrete tests being implemented are the Slump Flow test, V Funnel and the L- Box test. The results for each mix are shown in **Table 4.** All mix meets the requirements proposed by The European Guidelines for Self Compacting Concrete (2005), which reference standard is European Standard.

Table 4: Results on the fresh concrete properties

Test	Slump Flow Test (mm)		V – Funnel (s)	L – Box (mm)	
	X-direction	Y-direction		PL	BL
Mix 1	620	590	11.00	0.99	0.01
Mix 2	770	660	9.07	0.78	0.01
Mix 3	610	620	6.50	0.40	0.78
Mix 4	800	800	3.56	0.40	0.4
Mix 5	600	600	14.00	0.34	0.11

4.1.1 Slump Flow Test

The slump flow spread *S* is the average of largest diameters of the spread, d_{max} and diameter of the spread in a direction perpendicular to the first one, d_{perp}, as shown below. *S* is expressed in mm to the nearest 5 mm.

$$S = \frac{dmax+dperp}{2}$$

The higher the slump flow spread, the greater is the filling ability of fresh mix. Most SCCs requires require a slump flow > 600mm to achieve an adequate filling ability.

As shown in **Table 4**, the result of slump flow diameters came out as 590mm – 800 mm at all mixes, which satisfied the requirement of self-compacting concrete as stipulated by European guidelines. As shown in **Table 5**, the design mix that satisfied the range for precision of the slump flow test.

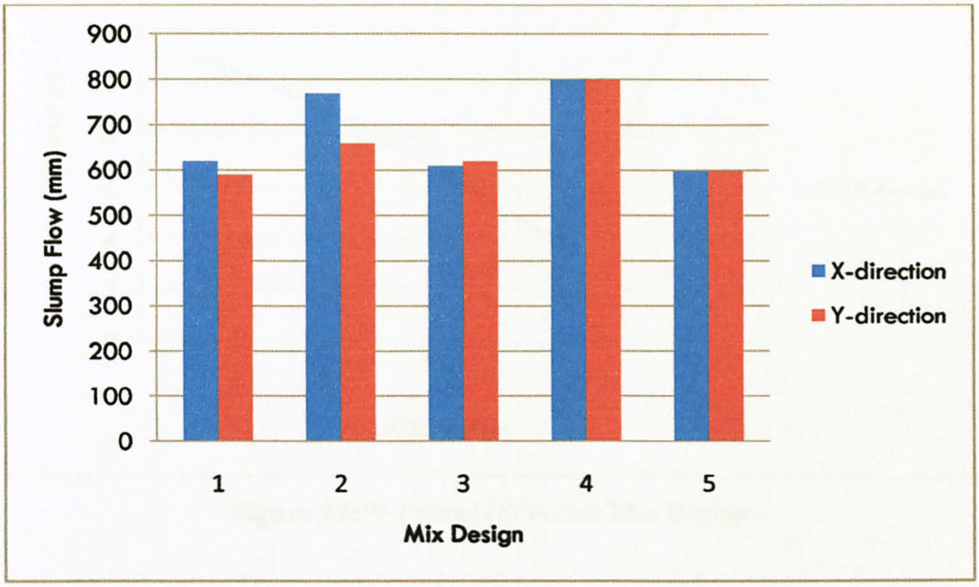

Figure 22: Slump Flow (mm) versus Mix Design

Table 5 Precisions of Slump flow spread and time

Slump flow spread *S* [mm]	**< 600**	**600-750**	**>750**
Slump flow time T50 [sec]	***≤3.5***	***3.5-6***	***>6***

4.1.2 V-Funnel

A direct test result (V-Funnel flow time t_v) is obtained and no need for further processing. The V-funnel flow time t_v measures filling ability and flow-rate of a fresh mix. The flow rate is strongly related to plastic viscosity. A substantial increase of may indicate a partial blocking caused by increased concentration of coarse aggregate at the bottom of the funnel.

The requirement for V-Funnel test is 8 to 15 seconds and most of the results of mix shown below are within range even though Mix#4 show gave the least precise result. The reason of this apparently because of high amount of moisture content.

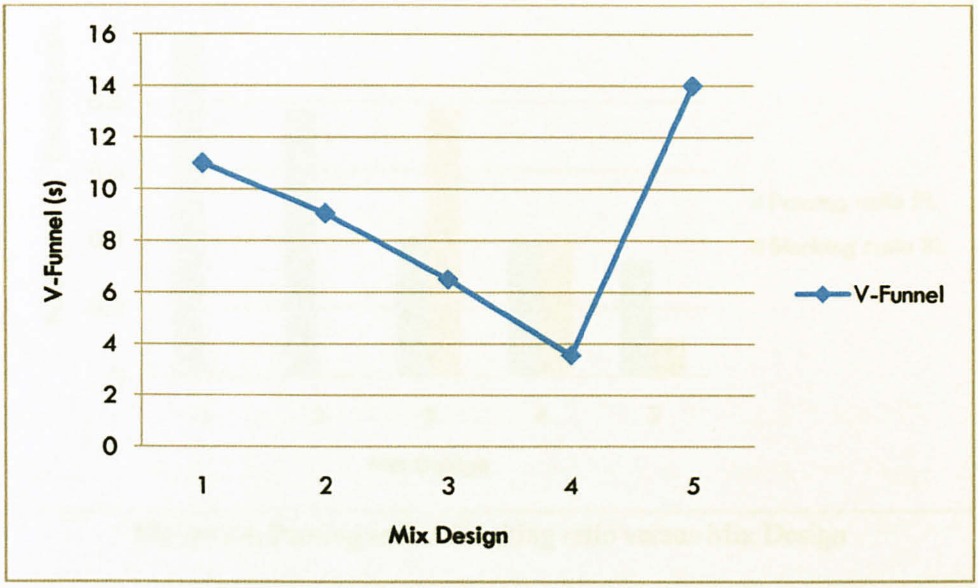

Figure 23: V-Funnel (s) versus Mix Design

Table 6 Precisions of the V-funnel flow time

V-Funnel flow time, tV [sec]	3	5	8	12	≥15

4.1.3 L-Box

As shown in **Table 7**, the value of ratio which is around $0.7 \leq PL \leq 0.9$ expected value or normal fresh concrete value expected. The value that larger than 0.08 considered have low blocking ability and for value lower than 0.8 considered have high blocking ability. From **Table 7**, the only mix that satisfied the requirement is Mix#2.

The SCC mixtures exhibited good ability to flow through the rebar of the L-Box. The passing ratio P_L or blocking ratio B_L is calculated using this equation expressed in dimensionless to the nearest 0.01.

$$PL = \frac{H}{Hmax} \quad BL = 1 - \frac{H}{Hmax}$$

The drawback of the result is that any slight deviation from horizontal of the trough of the apparatus significantly affects the test results.

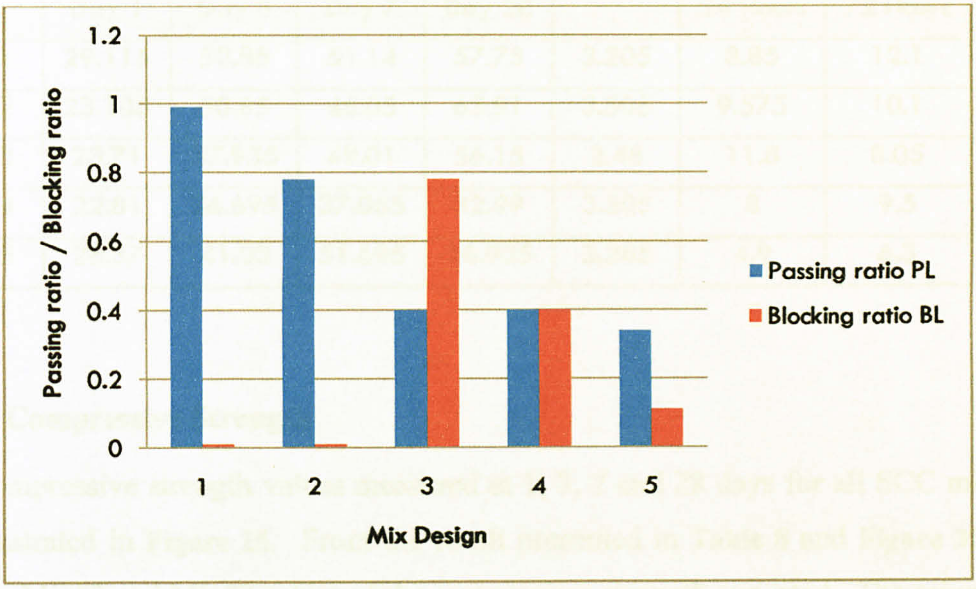

Figure 24: Passing ratio / Blocking ratio versus Mix Design

Table 7 Precisions of the L-box passing or blocking ratio

Passing ratio P_L	**1**	**0.9**	**0.8**	**0.7**	**<0.65**
Blocking ratio B_L	**0**	**0.1**	**0.2**	**0.3**	**>0.35**

4.2 HARDENED CONCRETE TEST

Compressive strength results shown in **Table 8** are average values obtained on at least two specimens at each day, results of porosity are average values obtained on two 1 inch cylinder core specimens tested. Chloride migration results are average values obtained on two specimens measured each section at 10 points from the visible white silver chloride precipitation.

Table 8: Summary of Hardened Concrete test result

Mix	Compressive Strength (Mpa)				Porosity (%)	Chloride Migration Depth Penetration		
	Day 1	Day 3	Day 7	Day 28		24 Hours	72 Hours	7 Days
Mix 1	29.115	50.85	51.14	57.75	3.205	8.85	12.1	12.85
Mix 2	23.105	50.85	45.05	63.91	3.505	9.575	10.1	12.75
Mix 3	23.71	37.935	49.01	56.15	2.48	11.8	8.05	11.7
Mix 4	22.81	36.695	37.055	42.99	3.505	8	9.5	11.8
Mix 5	28.37	41.03	51.695	58.935	3.285	4.9	6.3	10.2

4.2.1 Compressive Strength

The compressive strength values measured at 1, 3, 7 and 28 days for all SCC mixtures are illustrated in **Figure 25**. From the result presented in **Table 8** and **Figure 25**, only Mix#1, Mix#2 and Mix#3 achieved the compressive strength expected. The mixes gave result 57.75 MPa, 63.91 MPa and 56.16 MPa. Mix#4 shows the lowest compressive strength. The reason for this apparently due to high amount of moisture content that showed during mixing.

It is suggested that long term monitoring of the compressive strength of self-compacting concrete made incorporating PFA and RHA be conducted to better understands the kinetics of strength development in such mixtures.

After 28 days, the reached compressive strength of SCC and normal vibrated concrete of similar composition does not differ significantly in the project.

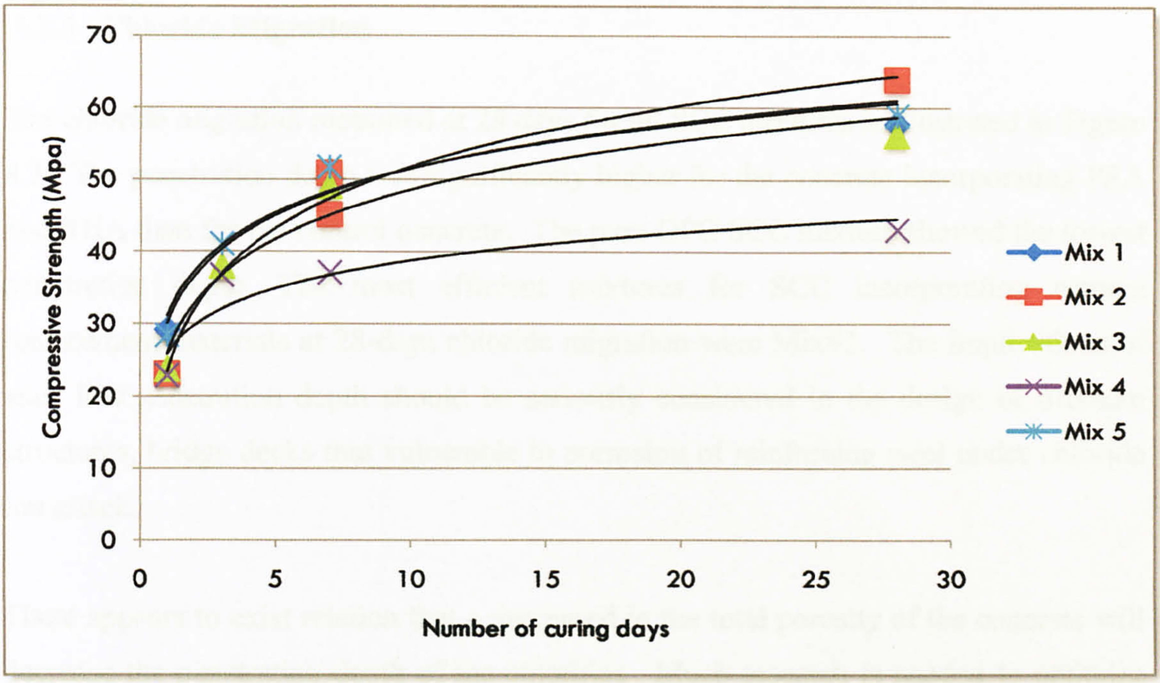

Figure 25: Compressive strength versus time for the various SCC mixtures

4.2.2 Porosity

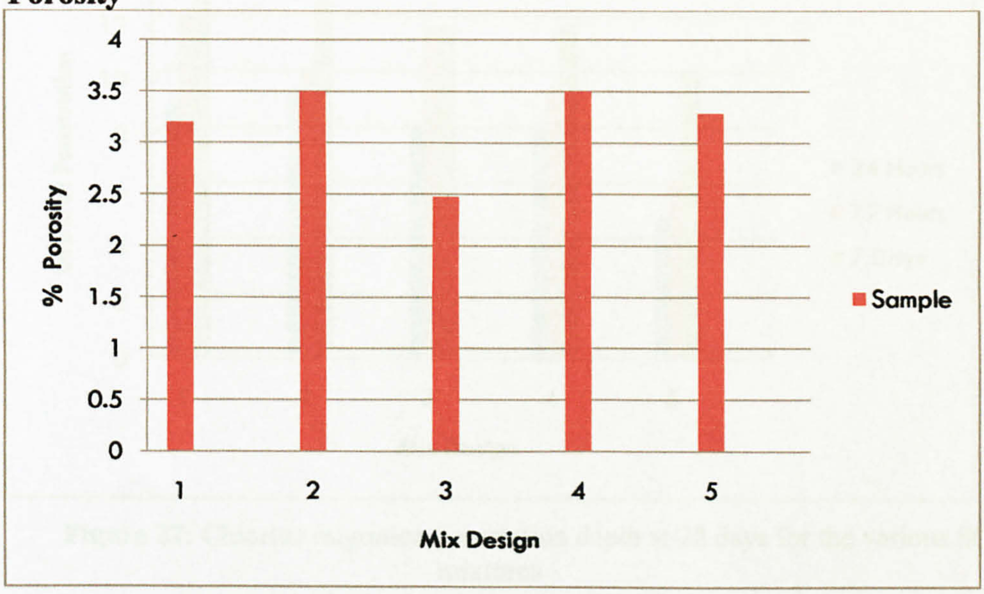

Figure 26: Porosity result

Porosity of the mixes show positive to compressive strength. Which is the percentage of porosity should be decrease proportionately with compressive strength. All the data percentage is as presented in **Figure 26.**

4.2.3 Chloride Migration

The chloride migration measured at 28 days for all SCC mixtures is illustrated in Figure 4.3. The penetration depth was significantly higher for the concrete incorporating PFA and RHA than for the control concrete. The pure OPC SCC mixture showed the lowest penetration depth. The most efficient mixtures for SCC incorporating cement replacement materials at 28-days chloride migration were Mix#3. The implications of such low penetration depth should be seriously considered in the design of offshore structures, bridge decks that vulnerable to corrosion of reinforcing steel under chloride ion attack.

There appears to exist relation that a decreased in the total porosity of the concrete will decrease the penetration depth of the chlorides. Much research is needed to optimize such effects and understand the mechanisms underlying them.

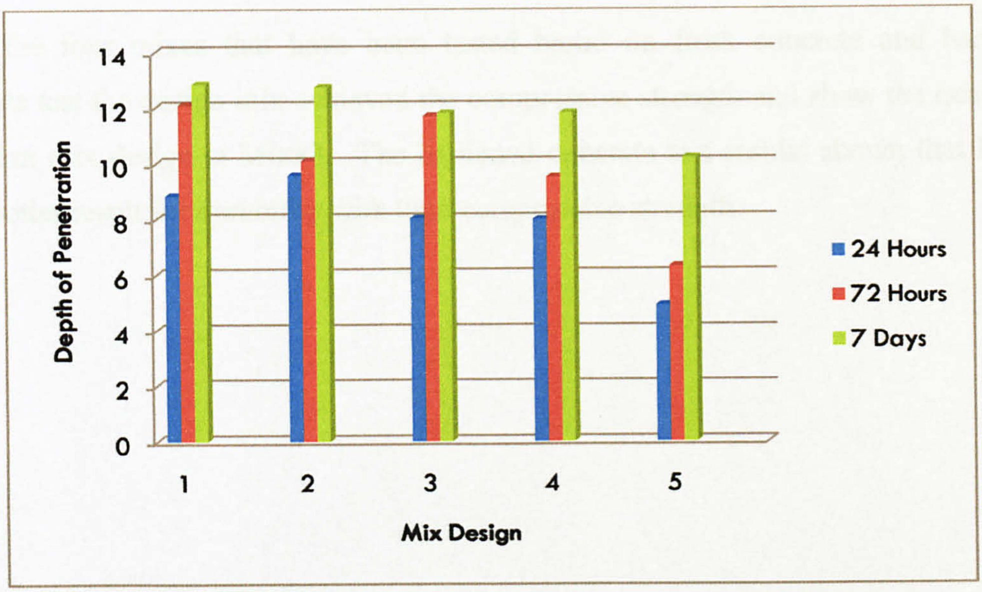

Figure 27: Chloride migration penetration depth at 28 days for the various SCC mixtures

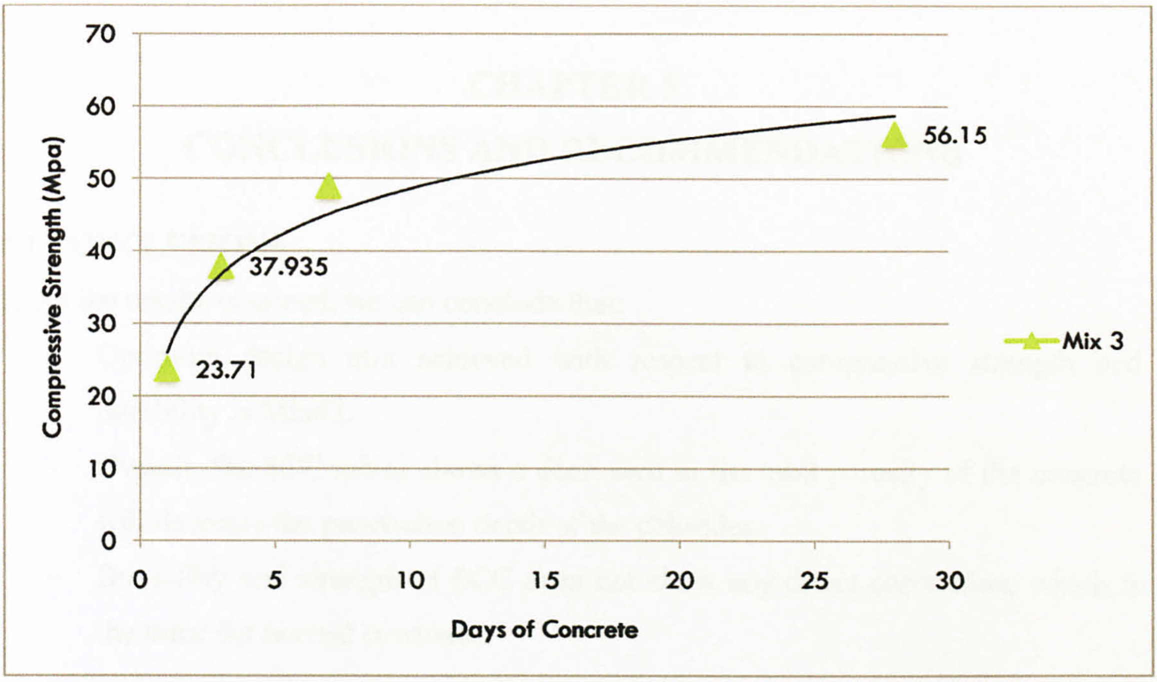

Figure 28: Result of Compressive Strength optimum mix design

From the four mixes that have been tested based on fresh concrete and hardened concrete test the design mix achieved the compressive strength and show the quality of optimum mix design is Mix#3. The hardened concrete test results shown that Mix#3 have better result for durability with high compressive strength.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the results obtained, we can conclude that:

- Optimum design mix achieved with respect to compressive strength and durability is Mix#3.
- Overall, the SCC mixes shows a decreased in the total porosity of the concrete will decrease the penetration depth of the chlorides.
- Durability and strength of SCC does not show any direct correlation, which is the same for normal concrete.

These knowledge's brings a positive advantage in real life SCC application, with the addition of PFA, amount of cement used is reduced thus reduces the cost of concrete (although the uses of superplasticizers might offset the cost advantages, the overall cost advantages still apply). Then, with the incorporation of SCC, more durable structure precisely resistant can be built with less cost within less duration.

5.2 RECOMMENDATIONS

For this particular experiment, the author would like to recommend further testing of compressive strength test, porosity and chloride migration be conducted to gain a better understanding of the each testing.

Another recommendation is for future researches to use other corrosion measuring method. This somehow could justify the result of this particular experiment and points out any mistakes or miscalculations which might occur. The use of other corrosion mechanisms such as carbonation should be considered as the mechanism of attack is different than chloride attack.

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APPENDIX 1.0: DETAILS RESULTS OF COMPRESSIVE STRENGTH

Details results of compressive strength Mix#1

Day	Date	Weight (kg)	Optimum Weight (kg)	Stress (kN)	Average stress (kN)
1	13-Feb-2009	2.53	2.42	26.86	29.11
		2.31		31.35	
7	19-Feb-09	2.38	2.475	58.15	50.845
		2.57		43.51	
7	19-Feb-09	2.46	2.455	62.76	51.14
		2.45		39.52	
28	12-Mar-09	8.29	8.25	67.54	57.75
		8.21		47.96	

Details results of compressive strength Mix#2

Day	Date	Weight (kg)	Optimum Weight (kg)	Stress (kN)	Average stress (kN)
1	13-Feb-09	2.54	2.475	28.375	23.105
		2.41		17.83	
7	19-Feb-09	2.41	2.42	57.93	50.85
		2.43		43.77	
7	19-Feb-09	2.45	2.425	59.94	45.05
		2.4		30.16	
28	12-Mar-09	7.98	8.04	65.89	63.91
		8.1		61.93	

Details results of compressive strength Mix#3

Day	Date	Weight (kg)	Optimum Weight (kg)	Stress (kN)	Average stress (kN)
1	20-Feb-09	2.31	2.33	23.25	23.71
		2.35		24.17	
3	23-Feb-09	2.42	2.41	37.2	37.935
		2.4		38.67	
7	26-Feb-09	2.35	2.385	47.26	49.01
		2.42		50.76	
28	19-Feb-09	7.59	7.625	57.96	56.15
		7.66		54.34	

Details results of compressive strength Mix#4

Day	Date	Weight (kg)	Optimum Weight (kg)	Stress (kN)	Average stress (kN)
1	20-Feb-09	2.35	2.38	23.62	22.81
		2.41		22	
3	23-Feb-09	2.48	2.45	38.19	36.695
		2.41		35.2	
7	26-Feb-09	2.44	2.325	41.17	37.055
		2.21		32.94	
28	19-Mar-09	7.88	7.77	44.3	42.99
		7.66		41.68	

Details results of compressive strength Mix#5

Day	Date	Weight (kg)	Optimum Weight (kg)	Stress (kN)	Average stress (kN)
1	24-Feb-09	2.4	2.4	29.05	28.37
		2.4		27.68	
3	26-Feb-09	2.37	2.375	39.03	41.03
		2.38		43.03	
7	02-Mar-09	2.39	2.405	52.82	51.695
		2.42		50.57	
28	23-Mar-09	8.29	8.135	57.93	58.935
		7.98		59.94	

APPENDIX 2.0: DETAILS RESULTS OF POROSITY TEST

Details results of compressive strength Mix 1 on 26th March 2009

Sample No	Sample ID	Core dia (mm)	Core Length (mm)	Bulk Vol (cc)	Weight (g)	Grain Volume (cc)	Pore Volume (cc)	Grain density (g/cc)	Effective Core Porosity (%)
1	Mix 1	38.24	26.13	30.01	68.88	28.83	1.18	2.39	3.93%
2		38.22	26.05	29.89	69.18	29.15	0.74	2.37	2.48%
1	Mix 2	38.40	26.03	30.15	70.42	28.96	1.19	2.43	3.95%
2		38.26	26.18	30.10	71.16	29.18	0.92	2.44	3.06%
1	Mix 3	38.28	26.09	30.03	68.80	29.34	0.69	2.34	2.30%
2		38.29	26.17	30.13	69.11	29.33	0.80	2.36	2.66%
1	Mix 4	38.28	26.15	30.10	69.73	29.02	1.08	2.40	3.59%
2		38.15	26.11	29.85	70.06	28.83	1.02	2.43	3.42%
1	Mix 5	38.38	26.31	30.44	68.23	29.23	1.21	2.33	3.98%
2		38.22	26.20	30.06	68.74	29.28	0.78	2.35	2.59%

APPENDIX 3.0: DETAILS RESULTS OF CHLORIDE MIGRATION PENETRATION DEPTH

Details results of chloride migration for Mix#1

Days after 28 days	Date	Reading (mm)										Average spread (mm)
		1	2	3	4	5	6	7	8	9	10	
24 Hours	26-Mar-09	8	8	9	6	11	9	8	10	10	8	8.7
	26-Mar-09	8	14	6	11	10	12	6	9	8	6	9
72 Hours	29-Mar-09	11	10	6	12	12	14	13	12	7	14	11.1
	29-Mar-09	18	18	11	12	14	7	12	13	14	12	13.1
7 Days	02-Apr-09	8	12	8	6	9	21	17	13	17	13	12.4
	02-Apr-09	9	15	7	12	13	17	13	17	21	9	13.3

Details results of chloride migration for Mix#2

Days after 28 days	Date	Reading (mm)										Average spread (mm)
		1	2	3	4	5	6	7	8	9	10	
24 Hours	26-Mar-09	6	16	7	10	11	12	7	8	8	5	9
	26-Mar-09	5	10	12	16	9	9	11	11	11	8	10.15
72 Hours	29-Mar-09	3	7	9	5	14	7	8	8	11	20	9.2
	29-Mar-09	6	4	16	11	6	20	11	5	15	16	11
7 Days	02-Apr-09	15	16	12	15	17	20	19	7	15	8	14.4
	02-Apr-09	11	9	14	12	10	8	14	14	10	9	11.1

Details results of chloride migration for Mix#3

Days after 28 days	Date	Reading (mm)										Average spread (mm)
		1	2	3	4	5	6	7	8	9	10	
24 Hours	26-Mar-09	3	6	7	12	18	11	8	10	3	6	8.4
	26-Mar-09	8	6	6	4	5	9	8	14	10	7	7.7
72 Hours	29-Mar-09	7	8	3	20	14	8	17	8	18	14	11.7
	29-Mar-09	14	18	8	17	8	14	20	3	8	7	11.7
7 Days	02-Apr-09	20	18	11	6	14	13	8	14	5	8	11.7
	02-Apr-09	10	20	18	11	6	14	13	8	14	5	11.9

Details results of chloride migration for Mix#4

Days after 28 days	Date	Reading (mm)										Average spread (mm)
		1	2	3	4	5	6	7	8	9	10	
24 Hours	26-Mar-09	6	6	13	6	7	7	8	14	7	6	8
	26-Mar-09	6	13	6	7	7	8	14	7	6	6	8
72 Hours	29-Mar-09	11	6	11	6	6	9	10	13	12	11	9.5
	29-Mar-09	6	11	6	6	9	10	13	12	11	11	9.5
7 Days	02-Apr-09	5	10	17	15	24	12	5	15	10	5	11.8
	02-Apr-09	10	17	15	24	12	5	15	10	5	5	11.8

Details results of chloride migration for Mix#5

Days after 28 days	Date	Reading (mm)										Average spread (mm)
		1	2	3	4	5	6	7	8	9	10	
24 Hours	26-Mar-09	3	6	5	10	2	3	8	7	2	3	4.9
	26-Mar-09	6	5	10	2	3	8	7	2	3	3	4.9
72 Hours	29-Mar-09	7	7	8	6	2	6	7	6	6	8	6.3
	29-Mar-09	8	6	6	7	6	2	6	8	7	7	6.3
7 Days	02-Apr-09	3	5	5	9	10	12	19	4	12	23	10.2
	02-Apr-09	23	12	4	19	12	10	9	5	5	3	10.2