MECHANICAL PROPERTIES AND DURABILITY OF SELF COMPACTING CONCRETE CONTAINING SUPPLEMENTARY CEMENTITIOUS MATERIALS

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ABSTRACT

Self-compacting concrete (SCC) is a fluid mixture which is suitable for placing in structures with congested reinforcement without vibration. Self-compacting concrete development must ensure a good balance between deformability and compactability. The latter is affected by the characteristics of materials and the mix stability proportions and it becomes necessary to evolve a procedure for the mix design of SCC.

In this research, the engineering and durability performance of a grade 40 self-compacting concrete containing supplementary cementitious materials (SCM) as cement replacement were studied. Twenty seven trial mixes were conducted and four different mixes were then chosen for further investigation. They are SCC containing ordinary Portland cement (OPC), fly ash (FA), rice husk ash (RHA) and ground granulated blast-furnace slag (GGBS). Three different quantities of cement were used i.e. 440, 432, and 406 kg/m^3. For FA, RHA and GGBS, three different cement replacement levels were used i.e. 5%, 10% and 15%.

Different fresh concrete tests were conducted. Slump flow spread and V-funnel tests were used to determine the filling ability. L-box and J-ring tests were used to determine passing ability and segregation resistance. The results for fresh concrete showed that flowability of concrete increased with increasing binder materials and dosage of superplasticizer. Mechanical properties of self-compacting concrete such as compressive strength, flexural, splitting tensile, elastic modulus and drying shrinkage were investigated. Testing for compressive strength samples was conducted at 7 to 660 days; flexural tensile, splitting tensile strengths and elastic modulus were tested at 28 and 180 days. Drying

shrinkage was tested at ages of 7 to 360 days under two types of curing regimes, namely, air drying and water curing.

The performance criterion for passing ability was fulfilled for all SCM mixes concrete which contain FA, RHA and GGBS which were suitable for the segregation resistance requirement. The performance of mixture with FA, RHA and GGBS was better compared to those containing control mix (OPC). SCC containing 15% FA was the most effective to provide good filling ability and passing ability compared to mixtures containing RHA (10%) and GGBS (5%). Test results of hardened concretes also revealed that the compressive, splitting tensile and flexural strengths, static and dynamic modulus of elasticity, as well as ultrasonic pulse velocity increased whereas the water absorption and porosity decreased with lower W/B ratio and higher SCM content at 15%, 10% and 5% replacement of OPC by weight.

It was also shown that the relative strength of concrete containing SCM such as FA, RHA and GGBS immersed in sulphate solution increased with time compared to air dried specimens. In the drying shrinkage test for all mixes containing FA, RHA and GGBS, the reduction in weight is attributed to the formation of gypsum on the concrete surface which also results in the softening and spalling of the concrete surface. Consequently, experiments revealed that resistance chloride is reduced with increase of compressive strength of concrete containing various SCM particularly with FA and RHA compared to the control OPC mix.

The results for the hardened concrete containing SCM showed better strength at 2 years curing age. It yielded favourable outcome in drying shrinkage. Mixes subjected to magnesium sulphate solution showed better compressive strength compared to air dried mixes. In both comparison groups, mixes containing SCM yielded better outcomes compared to control mix. The permeability of SCC containing FA, RHA and GGBS was lower than that of control SCC concrete, thereby improving the durability properties and lowering the porosity of the concrete.

ABSTRAK

Konkrit pemadatan sendiri (SCC) adalah campuran cecair tanpa getaran yang sesuai untuk diletakkan dalam struktur yang sesak dengan tetulang. Pembangunan konkrit pemadatan sendiri perlu memastikan keseimbangan yang baik antara keupayaan berubah bentuk dan keupayaan memadat. Ianya dipengaruhi oleh ciri-ciri bahan dan perkadaran kestabilan campuran dan adalah perlu untuk merubah prosedur reka bentuk untuk campuran SCC.

Dalam kajian ini, prestasi kejuruteraan dan ketahan lasakan konkrit pemadatan sendiri bergred 40 yang mengandungi bahan-bahan pensimenar tambahan (SCM) sebagai pengganti simen telah dikaji. Dua puluh tujuh campuran percubaan telah dijalankan dan empat campuran yang berbeza kemudiannya dipilih untuk siasatan lanjut. Ini adalah SCC yang mengandungi simen Portland biasa (OPC), abu terbang (FA), abu sekam padi (RHA) sanga relau bagas berbutic terkisar (GGBS). Tiga kuantiti simen yang berbeza digunakan iaitu 440, 432, dan 406 kg / m^3. Untuk FA, RHA dan GGBS, tiga peringkat perggantian simen yang berbeza digunakan iaitu 5%, 10% dan 15%. Beberapa ujian konkrit segar yang berbeza telah dijalankan. Ujian penyebaran kemerosotan aliran dan ujian corong V telah digunakan untuk menentukan keupayaan pengisian. Ujian kotak L dan cincin J telah digunakan untuk menentukan keupayaan laluar dan rintangan pengasingan. Keputusan bagi konkrit segar menunjukkan bahawa kebolehaliran konkrit meningkat dengan peningkatan bahan pengikat dan dos super pemplastikan. Sifat mekanik konkirt pemadatan sendiri seperti kekuatan mampatan, lenturan, membelah tegangan belahan modulus kearjalan dan pengeringan pengecutan telah disiasat. Ujian untuk sampel kekuatan mampatan dijalankan dari 7 hingga 660 hari, kekyatan tegangan lenturan, tegangan

belahan dan modulus kearjalan telah diuji poda 28 dan 180 hari. Pengecutan pengeringan telah diuji pada umur 7 hingga 360 hari di bawah dua jenis rejim, pengawetan iaitu pengeringan udara dan pengawetan air.

Kriteria prestasi untuk keupayaan laluen telah dipenuhi bagi semua campuran konkrit SCM yang mengandungi FA, RHA dan GGBS yang sesuai untuk keperluan rintangan pengasingan. Prestasi campuran dengan FA, RHA dan GGBS adalah lebih baik berbanding dengan campuran kawalan (OPC). SCC yang mengandungi 15% FA adalah yang paling berkesan untuk menyediakan keupayaan pengisian dan keupayaan laluan berbanding RHA (10%) dan GGBS (5%).

Keputusan ujian konkrit terkeras juga mendedahkan bahawa kekuatan membelah belahan tegangan dan lenturan, modulus keanjalan statik dan dinamik, serta halaju denyutan ultrasonik meningkat manakala penyerapan air dan keliangan menurun dengan penururan nisbah W / B dan kandungan SCM lebih tinggi pada 15%, 10% dan 5% penggantian OPC.

Data juga menunjukkan bahawa kekuatan relatif konkrit mengandungi SCM yang direndam dalam larutan sulfat meningkat dengan masa berbanding dengan spesimen berudara kering. Dalam ujian pengecutan pengeringan untuk semua campuran yang mengandungi FA, RHA dan GGBS, pengurangan berat adalah disebabkan oleh pembentukan gipsum pada permukaan konkrit yang juga menyebabkan permukaan konkrit lembut dan meryerpih. Oleh itu, eksperimen menunjukkan bahawa rintangan klorida berkurangan dengan peningkatan kekuatan mampatan konkrit yang mengandungi pelbagai SCM terutamanya FA dan RHA berbanding dengan campuran kawalan OPC Keputusan bagi konkrit keras yang mengandungi SCM menunjukkan kekuatan yang lebih baik pada umur 2 tahun pengawetan. Ia membuahkan hasil yang menggalakkan dalam pengeringan pengecutan. Campuran terdedah kepada larutan magnesium sulfat menunjukkan kekuatan mampatan yang lebih baik berbanding dengan campuran berudara kering. Dalam kedua-dua kumpulan perbandingan, campuran yang mengandungi SCM membuahkan hasil yang lebih baik berbanding dengan campuran. Kawalan kebolehtelapan SCC mengandungi FA, RHA dan GGBS adalah lebih rendah berbanding dengan konkrit SCC terkawal, dengan itu meningkatkan sifat-sifat ketahanlasokan dan mengurangkan keliangan konkrit.

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Ec	Modulus of elasticity
FA	Fly ash
FM	Fineness modulus
fsp	Fractural splitting tensile strength
fc	Compressive strength,
GGBS	Ground granulated blast-furnace slag
I-Sat	Initial surface absorption test
MG	Magnesium sulphate
OPC	Ordinary Portland cement
p	Density
RC PT	Rapid chloride penetration test
RHA	Rice husk ash
RNSCC	Reference normal self compacting concrete
S	Slump
SCC	Self compacting concrete
SEM	Scanning electron microscopy
SP	Superplasticizer
SRF	Strength reduction factor
SSD	Saturated surface dry
TR	Trial and Error
UPV	Ultrasonic Pulse Velocity

υ	Poisson's ratio
W/P	Water powder ratio
XRF	X-ray fluorescence

CHAPTER 1: INTROUDUCTION

1. General

Self compacting concrete SCC is basically the outcome of long research that took place in Japan starting in the early 80s with a successful prototype completed in 1988 the shortage of skilled labors for compaction work and the increasing demands of designers in terms of complex structural members with high steel congestion wreathe main motivations behind the development of this ‘special concrete’. Nowadays, the use of self compacting concrete is not limited to Japan only; however that is where major research and developments are still taking place with the focus mainly on testing and mix design methods. The successful development of standards is the final step that is needed to fully exploit the properties of self compacting concrete where may this type of concrete will replace the ‘classic concrete’ and becomes the ‘standard concrete’ of the future.

Although the fundamental materials used in SCC have been in the practice for some time, this type of high-performance concrete has been in use only since the late 1980s. The first prototype was developed in Japan in 1988 as a response to the growing problems associated with concrete durability and the high demand for skilled workers (Ouchi, 2000). The durability of concrete, it was noted, is directly related to the degree and quality of consolidation efforts, which in turn is related to the skill level of the person operating the consolidation equipment. The apparent difficulty in attracting and retaining skilled workers compounds the problems with durability.

Unfortunately, many other parts of the world are also experiencing the same problems. As a result, additional research and advancements in SCC technology have since been made, most notably in Europe and in the United States; much of the research is being conducted by admixture manufacturers. Since the first prototypes were developed, many large-scale cast-in-place and precast-concrete projects have been completed using SCC with great success. We now know that it has tremendous potential for use in a wide variety of concrete operations including precast-concrete production.

The objective of this research is to improve the understanding of the properties of SCC containing FA and to provide information that could be used towards the commercialization of such concrete. The results indicate that it is possible to enhancement the mechanical properties and durability of SCC containing FA that is high performing in its fresh state. Furthermore, the addition of fly ash was shown to reduce superplasticizer dosage, increase workability and increase overall chloride permeability resistance. Fly ash has been reduces permeability bleeding, water demand workability, however strength development and the heat of hydration. It also improves is slower (Douglas et al., 2004). An experimental program, aimed at investigating the behavior of SCC fly ash FA has been carried out. The fresh state properties of the concrete were assessed using methods of segregation and flow. The rheology of the also characterized and compared with a previously developed paste paste matrix was rheology model finally; some hardened state properties of the concrete were evaluated.

Rice husk ash (RHA) contains 87 – 97% of silica with small amount of alkalis and other trace elements (Prasad, 2000). Based on temperature range and duration of burning of the husk, crystalline and amorphous forms of silica are obtained, which have different properties. It is important to produce ash with correct specifications for specific end use. From studies of the physical and mechanical properties of concrete with up to 10% replacement of cement with RHA, it has been reported that addition of RHA enhanced the strength and reduced water absorption of concrete(Givi, 2010). (Sampaio, 2002). Compared to silica fume with average particle size of 0.1 µm, RHA with particle size around 45 µm has three times higher surface area. Since RHA derives its pozzolanicity from its internal surface area, grinding of RHA to a high degree of fineness should be avoided (Mehta, 1979.)

The use of ground granulated blast furnace slag (GGBS), an industrial by-product, is well established as a binder in many cement applications where it provides enhanced durability, including high resistance to chloride penetration, resistance to sulphate attack (Wild, 1998) . Slag modifies the flocculation of cement, with a resulting reduction in the water demand. It reduces bleeding but leads to retardation at normal temperature, typically 30-60 minutes. The reactivity of GGBS at higher temperature is considerably increased. Steam curing of concrete containing GGBS can therefore be used. Prolonged moist curing of concrete containing GGBS is particularly important. Very good development of strength of concrete containing 50-75% of GGBS, with a total content of cementations material between 300-420 kg / m^3 has been reported. In view of the advantageous properties of GGBS, especially of improving workability and permeability of concrete, it has been utilized in this work.

Thus it is logical uses these elements lead to: maximizing concrete durability, conservation of materials resources waste and supplementary of cementing materials, and recycling of concrete. Waste and supplementary cementing materials such as fly ash, blast furnace slag, rice husk ash can be used as partial replacements for Portland cement And these materials can improve the durability of concrete by reducing the permeability of concrete

1.2 Problem statements

What is our goal?

The goals of this study are:

1. To study the feasibility of using RHA, FA, GGBS for producing SCC concrete. There are large quantities of industrial wastes in analyses such as FA, RHA, GGBS use to produces SCC related to solve environment problem

2. To determine a reasonable SCC mix design method using locally available industrial waste for use in precast concrete plants in Malaysia

1.3 Research Objectives

General Objective is to optimum mix proportion of using local Supplementary Cementitious Materials (SCM).

The main objective can be broken down into the following specific objectives:

- Evaluate mix proportion to get normal self compacting concrete (SCC) according to the Japanese mixing procedure
- To determine the suitable replacement of FA, RHA and GGBS to produce SCC of grade 40 MPa.
- Study the mechanical properties of SCC contains SCM such as compressive strength, tensile splitting, flexural strengths and elastic modulus.
- Evaluate the durability properties of SCC concrete such as porosity, ISAT, Absorption, Magnesium sulphte and RCPT.
- Evaluate the time dependent properties drying shrinkage and expansion at SCC concrete.

1.4 Research significance

SCC is a special type of concrete that needs more cementitious materials to obtain sufficient flowing ability, high strength and durability investigate the suitable replacement 15%, 10%, 5% according to Japanese standard by using additional materials such as FA, RHA and GGBS respectively to produce concrete SCC grade 40 Have been in this study. Due to the rising price of cement, researches are enduring all over the world on the replacement of cement with suitable SCM in SCC. SCM can reduce bleeding and thus improving the segregation resistance of SCC. Moreover, SCM can improve the hardened properties and durability of concrete. In this context, fly ash, rice husk ash and ground granulated blast-furnace slag, have been used successfully in producing SCC.

The results for the hardened concrete containing SCM showed better strength at 2 years curing age. It yielded favourable outcome in drying, shrinkage and expansion creep. Mixes subjected to magnesium sulphate solution MS showed better compressive strength compared to air dried mixes. In both comparison groups, mixes containing SCM yielded better outcomes compared to control mix. The permeability of SCC containing FA, RHA and GGBS were lower than that of control SCC concrete, thereby improving the durability properties and lowering the porosity of the concrete and increasing the resistant chloride penetration.

1.5 Scope of Research

The scope of work of this study can be subdivided into three parts. The first part is focused around Literature review of the related studies. The second part of the scope of work is laboratory works. The third part experimental work includes characterization of aggregate and supplementary cementitious materials FA, RHA and GGBS

The Effects of replacement, w/p, cement content, aggregate size, aggregate ratio, mixing Approach on engineering properties of fresh and hardened concrete will be investigated in order to establish a guide line for optimization of SCC concrete. Several standard tests were conducted according to international standards such as European guidelines 2005, ASTM and BS to assess the properties of fresh and hardened SCC. This test includes compressive strength, flexural strength, splitting strength and durability of hardened SCC concrete tests. The results obtained from this research will be analyzed using the descriptive analysis and regression analysis using Excel. The thesis is organized in the six chapters. A brief description of the content of each chapter is given below:-

Chapter 1 provides the general background and motivation for this work. The objectives of the research, problem statement, research significance and scope of research and the organization of the thesis are presented.

Chapter 2 provides thorough information about the background needed for conducting this research. It presents information about self compacting concrete, which has special properties that can be distinguished when used the of agricultural wastes such as FA, RHA and GGBS

Chapter 3 explains the research and discusses the methodology adopted this chapter also describes the materials used in this research, the methods of preparing the specimens, and the method of testing and analysis of the results

Chapter 4 focuses on the results and discussion for characteristic materials, mix design fresh properties concrete and mechanical properties obtained in this study also shows the experimental results of the testing setup

Chapter 5 focuses on the durability of hardened SCC concrete results obtained this chapter shows the experimental results of the testing setup

Chapter 6 summarizes the findings obtained from the results of this study and draws the main conclusion of this research.

2.1 Introduction

Self Compacting Concrete, produced in Japan in late 80's to solve problems of pouring and setting concrete in high rebar densities structures, has slowly spread all over the world, showing many other characteristics. The most relevant performances of SCC are already well known and have been confirmed in large scale applications. High filling capacity, no vibration needed reduced noise and unhealthy tasks for workers, high flow for longer distance pouring, homogeneity due to absence of poor workmanship in casting, high strength and durability and excellent surface are the product's advantages.

Large amounts of untreated waste from agriculture and industrial sector contaminate land, water and air by means of leaching, dusting, and volatilization. Improper treatment of these wastes causes similar problems. This ultimately causes pollution and is harmful to the ecosystem. Environmental regulations have also become more stringent, causing this waste to become increasingly expensive to dispose. Therefore, exploitation of this waste material as sustainable building material in the construction industry helps preserve the natural resources and also helps maintain the ecological balance Legislative control of pollutants has to be determined to prevent or to minimize the transfer of hazardous material to other areas. Pollution also damages ecosystems. A concrete using agricultural wastes that are abundant in an agro-based country such as Malaysia presents an interesting alternative to the conventional lightweight concrete (Nontananandh, 1990).

Rice husk is an agro-waste material which is produced in about 100 million of tons. Approximately, 20 kg of rice husk are obtained for 100 kg of rice. Rice husks contain organic substances and 20% of inorganic material. Rice husk ash (RHA) is obtained by

The combustion of rice husk. The most important property of RHA that determines pozzolanic activity is the amorphous phase content. RHA is a highly reactive pozzolanic material suitable for use in lime-pozzolanic mixes and for Portland cement replacement. RHA contains some amount of silicon dioxide, and its reactivity related to lime depends on a combination of two factors, namely the non-crystalline silica content and its specific surface (Tashima, 2004).

Rice husk ash (RHA) has been used as a highly reactive pozzolanic material to improve the microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in self compacting concrete. Mechanical properties of RHA blended Portland cement concretes revealed that in addition to the pozzolanic reactivity of RHA (chemical aspect), the particle grading (physical aspect) of cement and RHA mixtures also exerted significant influences on the blending efficiency. The scope of this research was to determine the usefulness of RHA in the development of economical self compacting concrete (SCC). The cost of materials will be decreased by reducing the cement content by using waste material like rice husk ash (Ahmadi, 2007).

Fly ash is the finely divided residue resulting from the combustion of coal. It is a pozzolanic material that is commonly used in cement- based materials and the particles are generally finer than cement particles Fly ash is approximately half the price of its economical benefits, the use of fly ash in has been reduces cement, and in addition to permeability bleeding, water demand and the heat of hydration. It also improves workability however strength development is slower However, not all fly ash is varies suitable for concrete, and because the chemical composition of fly ash widely ASTM C 618 provides a classification system based on its coal source.

Ground granulated blast furnace slag (GGBS) is a waste product in the manufacture of pig iron, about 300 kg of slag being produced for each tone of pig iron. When this slag is rapidly quenched and ground, it will possess latent cementatious properties. After processing, the material is known as GGBS whose hydraulic properties may vary and can be separated into grades.

This chapter provides the background and literature review of the thesis. It gives a description of the general objectives for this study. The use of SCC with various admixtures material, namely RHA, FA and Ground Granulated Blast-Furnace Slag (GGBS) in varying percentages to reduce environmental pollution and enhance the mechanical properties, durability and the workability of SCC concrete, besides reducing the cost. Finally, a summary of literature is presented.

In this study, using various admixtures with SCC concrete such as RHA, FA, and GGBS improved its strength and durability due to the increase in binder ratio, which leads to the voids being filled by the mixes. Also, the cost of self compacting concrete is reduced and a concrete grade of 40 MPa is obtained.

2.2 History of self-compacting concrete

The history and development of SCC can be divided into two key stages: its initial development in Japan in the late 1980s and its subsequent introduction into Europe through Sweden in the mid- to late-1990s.

SCC was first developed in Japan in 1988 in order to achieve more durable concrete structures by improving the quality achieved in the construction process and the placed material (Okamurah et al., 2000). The removal of the need for compaction of the concrete reduced the potential for durability defects due to inadequate compaction (e.g. honeycombing). The use of SCC was also found to offer economic, social and environmental benefits over traditional vibrated concrete construction.

The first research publications that looked into the principles required for SCC were from Japan and are dated around 1989 to 1991. These studies concentrated upon high performance and super-workable concretes and their fresh properties such as filling capacity, flowability and resistance to segregation(Tanigawa, 1990), (Tangtermsirikul, 1991).

A conference was recently held in Japan in October 2002 on Concrete Structures in the 21st Century, which contained six papers on SCC, including four from Japan (Proceedings Congress, Osaka, 2002). These papers illustrated that the basic technology of the material in Japan is relatively well understood and that the majority of current efforts in research and development are concentrated on taking this knowledge further into new applications such as composite structures and sheet piling.

In the second half of the 1990s, interest and use of SCC spread from Japan to other countries, including Europe. Some of the first research work to be published from europe was at an International RILEM (International Union of Testing and Research Laboratories of Materials and Structures) conference in london in 1996. Papers were presented on the design of SCC by University College lo (Domone, 1996) and a mix-design model by the Swedish Cement and Concrete Research Institute (CBI).

As described earlier, Sweden was at the forefront of the development of SCC outside Japan and it is estimated that SCC now accounts for approximately 7–10% of the Swedish ready-mix market (Skarendahl & Billberg, 2006), up from approximately 3% in 2000. Currently, the CBI, four universities and the government in Sweden are all conducting research into SCC.

France is quite active in the research and development of SCC (de Larrard & Sedran, 2002). A national research project on SCC called BAP (Be´tons auto-plac¸ants) is currently ongoing. French recommendations for the use of the material were established in July 20003 and are used as reference on construction sites.

In Germany, SCC requires technical approval before it can be used on site (Reinhardt, 2002). The current DIN standards do not allow this type of concrete to be used because the consistency and the fines content do not comply with the standard. Therefore, the DIBt (German Institute of Technical Approvals in Berlin) requires suitability tests from a third-party laboratory, usually universities, who then issue an official approval. Many contractors have obtained approvals and are constructing with SCC.

In order to produce SCC, the parameters that need to be examined are the type of cement, aggregate superplasticizer and all the binders used with the concrete. In this study, Malaysian material is used to produce SCC of grade 40 MPa. Table 2.1 shows the Guideline of SCC and specification development in Europe standard 2002

Table 2.1: Guideline of SCC and specification development in Europe standard 2002

Country guideline	Organization	Acceptance phase	Publication date
Austria	N/A	Draft	2002
Denmark	N/A	Draft In Preparation	n/a
Europe	EFNARC	Guideline	2002
Finland	N/A	Draft	2003
France	AFGC	Industry Recommendation	2000
Germany	ANNEX TO DIN 1045	For Comment	2003
Italy	ANNEX TO EN 206	For Comment	2003
	Italian ready-mix ASSOC.	In Preparation	n/a
Netherlands	BRL 1801	Approval	2002
	TC 73/04	Accepted	2001
Norway	Norwegian Concrete Society	Accepted	2002
Sweden	Swedish Concrete Assoc(SCA)	Accepted	2002

2.3 Compaction grade and specimens

The structure of concrete is highly influenced by the presence of voids due to incomplete compaction. Compaction grade 1 is the perfect compaction obtained preparing test specimens, but when pouring concrete in a wall, a slab or a column compaction is more difficult. Depending on consistence class and accuracy of compaction, both by means of vibrating pokers in the concrete or external vibrators applied to the formwork the resulting compacting grade can spread from 0.93 to 0.98 (Collepardi M, 2001). As a consequence of a compaction grade less than 1, strength will be reduced about 5% for every 0. 01 for a grade 0.97 a reduction of 15% in strength has to be expected in the structure. Moreover, the compacting grade will not be uniform for SCC, the possibility of reaching compaction grades close to 1 is confirmed: weight of SCC specimens is same or higher than accurately vibrated standard concrete ones.

When we produce the SCC in this study, the compacting factor is an important parameter. When we conduct testing of the fresh concrete, it must be in accordance with the standard limits of compacting and workability properties of grade 40 SCC

2.4 Ingredients of self compacting concrete.

Concrete is a mixture of several components. Water, portland cement and fine and coarse aggregates form ordinary concrete mixture. Various chemical and mineral admixtures, as well as other materials such as fibers, also may be added to the normal concrete mixture to enhance certain properties of the fresh or hardened concrete(Chopin, 2004).

Other ingredients can be added to enhance some of the properties of normal concretes such as fly ash, ground granulated blast-furnace slag, super plasticizers and silica fumes(Wang & and Tsai, 2006), (Hwang & Hung, 2005),(Neville, 1995)

In this study RHA, FA and GGBS with the normal Portland cement are used to produce a new type of concrete with various ratios of admixture filler to enhance the mechanical properties, durability and workability of the concrete.

2.4.1 Cement content

The major constituent of concrete is cement, which is made up of calcium, silica, alumina, and iron oxide. Ordinary Portland cement is the most common cement in use. about 90 % of all cement used in USA and England is ordinary Portland cement (Neville, 1995). Several types of Portland cement are available commercially and additional special cements can be produced for specific purposes.

Commercial cement meeting the ASTM C150 (2004) Standard Specification for Type I Portland cement varies considerably in chemical composition and fineness. This variation influences the water requirement for normal consistency. The exact effect of a water reducing agent on water requirement depends on the cement characteristics. The performance of concrete is also a function of cement content. The cement content in concrete is in the range of 280 to 557 kg /m^3 (R.-. ACI, 1995) . In this study, the Malaysian cement Type 1 YTL is produced, according the Malaysian standard.

2.4.2 Water

Water is essential in the production of concrete to initiate the chemical reactions. with cement, to wet aggregate and to lubricate the mixture for easy workability, drinking water is normally used in mixing. Water having harmful ingredients, contamination, silt, oil, sugar or chemicals is destructive to the strength and setting properties of cement. It can disrupt the affinity between the aggregate and the cement paste and can adversely affect the workability of a mix(E. G. Nawy, 1996).

The sources of water for concrete are basically three: added water, moisture present in aggregates and moisture present in liquid super plasticizer. The added water is generally required to comply with the standard set forth by the British Standard Institution (BS, 1980,1985). According to this standard, added water should preferably be potable or clean, fresh and free of obvious contaminants. If mortar cubes made with water have 7-day strengths at least equal to 90% of the compressive strength of the specimens made with distilled water, the water then can be considered suitable for making concrete (Hwang & Hung, 2005). Some specifications also accept water for making concrete if the pH value of the water lies between 6 and 8 and the water is free from organic materials(Shetty, 1993). A key function of water is to bond the mixtures added to concrete.

2.4.3 Effect of aggregate ratio on SCC

The density of the recycled aggregates is lower than the natural aggregates and the recycled aggregates have a greater water absorption value compared to the natural aggregates. As a result, a proper mix design is required for obtaining the desired qualities for concrete made with recycled aggregates (Lin, 2004),(Bairagi, 1990).

Factors influencing the density and compressive strength of aerated concrete made up of fly ash and lime/cement ratio have also been reported by Zhang (1990), who concluded that the compressive strength was a function of the density of concrete and an increase of density resulted in higher compressive strength. Concrete made up of 25% PA replacement for natural aggregate and a 350 kg/m^3 higher cement dosage is needed to supply compressive strength required for structural lightweight aggregate concrete, (Curcio, 1998).

Thus, all the research points to the importance of the ratio of aggregates used in determining the quality of concrete used. In this study, a ratio of 55% fine and 45% coarse aggregate is used after working with trial mixes to produce 40 MPa grade SCC.

2.4.4 Influence of coarse aggregate.

It is not always possible to predict the degree of compaction in a structure by using the test results showing the degree of compaction of the concrete used in the structure, since the maximum size of coarse aggregate is close to the minimum spacing between the reinforcing bars of the structure. The relationship between coarse aggregate content in concrete and the filling height of the Box-type test is the standard index for self-compactability of fresh concrete. The test results show that the influence of coarse aggregate on the flowability of fresh concrete largely depends on the size of the spacing of the obstacle. The self-compactability of fresh concrete has to be discussed in terms of solid particles as well as in terms of liquid (Hajime et al 2003)

The size of the coarse aggregate is an important factor in determining the flowability of concrete through the reinforcement bar. In this study, the size of coarse aggregate is determined after the trial mixes indicate the suitable size (5-14 mm) to produce the concrete.

The influence of coarse aggregate on the self compatibility of fresh concrete, especially flowability though obstacles, can be equal despite the shape of the coarse aggregate particles as long as the ratio of coarse aggregate content to its solid volume in concrete is the same.

However, the influence of the grading of coarse aggregate must also be considered if the spacing of the obstacles is very close to the maximum size coarse speed

Aggregate Figure 2.1 shows that. The relationships between the size of the concrete funnel's outlet and flow through it depends on the fineness modulus of coarse aggregate FM of concrete even if the property of the mortar phase is the same . It was found out that the flow speed of the concrete through the funnel with an outlet width of 55 mm was largely influenced by the grading of the coarse aggregate (Alawneh, 2004).

Figure 2.1: Different shapes and sizes of coarse aggregate

In this research, local gravel that meets the Malaysian standard has been selected. The pertinent factors to be considered are the chemical specifications, size, and shape. Additionally, the materials must be free of clay, which has a negative impact on the engineering specifications of the concrete.

2.4.6 Surface properties of the aggregate

Surface properties of the aggregates affect the workability of concrete and the bond between the pastes and aggregate, which is one of the main reasons behind lightweight aggregate concrete's mechanical strength. It is thus not desirable to have a

Perfectly smooth aggregate, but it should not be completely irregular and open either. The latter would result in lots of paste penetrating into the pores of the grain. This mortar would not improve workability but density would increase (Weigler & Karl, 1972).

Ideally, the aggregate particles should be spherical, with a hard and closed external skin providing a good bond with the cement paste, while the interior of the particles should have a high proportion of voids (high internal porosity) (Beaudoin, 1979).

2.4.7 Rice Husk Ash.

Rice is the primary source of food for billions of people around the world. Rice husk is the shell produced during dehusking of paddy. Globally about 600 Mt of paddy is being produced annually and this figure is increasing annually. India is the second largest producer of rice, next to China.

Rice husk is amenable for value addition so that national economy may grow its uses without conversion or with conversion (ash form) are many. Most of the husk from the milling is either burnt or dumped as waste in open fields and a small amount is used as fuel for boilers, electricity generation, bulking agents for composting of animal manure etc(Asavapisit & Ruengrit, 2005).

The exterior of rice husk is composed of dentate rectangular elements, which themselves are composed mostly of silica coated with a thick cuticle and surface hairs. The mid region and inner epidermis contain little silica. Plants absorb various minerals and silicates from earth into their body

Inorganic materials, especially silicates are found in higher proportions in annually grown plants, such as, rice, wheat and Sunflower, than in long–lived trees Inorganic materials are found in the form of free salts and particles of cationic groups combined with the anionic groups of fibres in the plants. The silica occurs in several forms within the rice husks at the molecular level and it is associated with water. In nature, the polymorphs of silica are quartz cristobalite, tridymite, coestite, stishovite, lechatelerite (silica glass) and opal. It is this silica concentrated in husk by burning which makes the ash so valuabl

Paddy on an average consists of about 72 % of rice, 5– 8 % of bran, and 20 – 22 % of husk (C S Prasad, 2000). It is also estimated that every ton of paddy produces about 0.20 ton of husk and every ton of husk produces about 0.18 t to 0.20 tone of ash, depending on the variety, climatic conditions, and geographical location (Prasad, 2000),(Bouzoubaâ & Fournier, 2001)

Rice husk ash (RHA) contains 87 – 97% of silica with small amount of alkalis and other trace elements (Prasad, 2000). Based on temperature range and duration of burning of the husk, crystalline and amorphous forms of silica are obtained, which have different properties. It is important to produce ash with correct specifications for specific end use.

When rice husk ash is used, the ratio of silica (SiO_2) is an important factor to be considered, as it significantly affects the strength of the concrete. Also, rice husk ash Does not have a high percentage of salt in this thesis, rice husk ash that satisfies Malaysian property standards are used.

Table2.2: Comparisons of chemical properties of RHA from various locations

Constituents	Weight, %						
	Malaya 3	Brazil 13	Netherlands 29	India 5	Iraq 20	USA 28	Canada 17
Silica as SiO_2	93.10	92.90	86.90	90.70	86.80	94.50	87.20
Alumina $Al2O_3$	0.21	0.18	0.84	0.40	0.40	Trace	0.15
Iron as $Fe2O_3$	0.21	0.43	0.73	0.40	0.19	Trace	0.16
Calcium as CaO	0.41	1.03	1.40	0.40	1.40	0.25	0.55
Potassium K_2O	2.31	0.72	2.46	2.20	3.84	1.10	3.68
Magnesium MgO	1.59	0.35	0.57	0.50	0.37	0.23	0.35
Sodium as Na2	*	0.02	0.11	0.10	1.15	0.78	1.12
Sulphur as SO_3	*	0.10	*	0.10	1.54	1.13	0.24
Loss on ignition	2.36	*	5.14	4.80	3.30	*	8.55

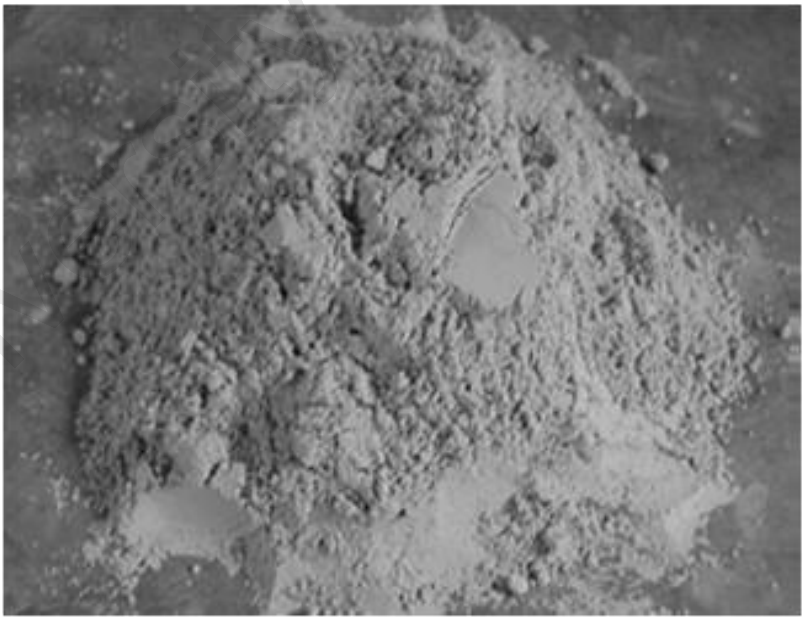

Figure 2.2: Sample of RHA after grinding

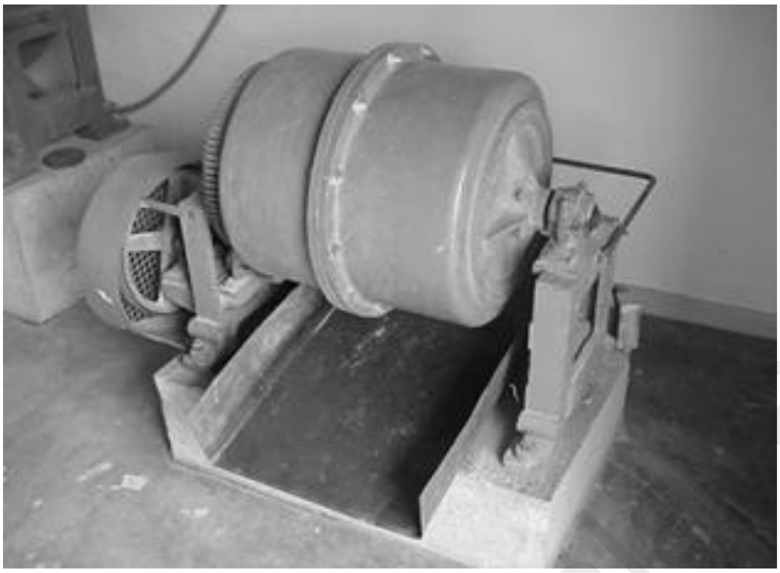

Figure 2.3: A ball mil

2.4.7.1 RHA for cement and construction industries

From studies of the physical and mechanical properties of concrete with up to 10% replacement of cement with RHA, it has been reported that addition of RHA enhanced the strength and reduced water absorption of concrete(Givi, 2010). (Sampaio, 2002) studied the strength and durability characteristics of concrete with up to 20 % replacement of RHA. The strength was found to increase with on increase of RHA replacement levels. (Coutinho J S 2003) showed that the performance of RHA in terms of strength and chloride permeability to be better than the concrete admixed with silica fume.

Table 2.3: Top ten countries, producer of the rice husk in the world

Country	Rice, paddy production in 2002 (t)	Percentage of total paddy production %	Percentage of total paddy production (%)	Potential ash production (18% of husk)
China,	177,589,000	30.7	35,517,800	6,393,204
India	123,000,000	21.2	24,600,000	4,428,000
Indonesia	48,654,048	8.4	9,730,810	1,751,546
Bangladesh	39,000,000	6.7	7,800,000	71,404,000
Vietnam	31,319,000	5.4	6,263,800	1,127,484
Thailand	27,000,000	4.7	5,400,000	972,000
Myanmar	21,200,000	3.7	4,240,000	763,200
Philippines	12,684,800	2.2	2,536,960	456,653
Japan	11,264,000	1.9	2,252,800	405,504
Brazil	10,489,400	1.8	2,097,880	377,618
USA	9,616,750	1.7	1,923,350	346,203
Korea	7,429,000	1.3	1,485,800	267,444
Pakistan	5,776,000	1.0	1,155,200	207,936

2.4.7.2 Incinerating conditions of RHA

Studies have shown that burning rice husk below 700°C yields amorphous ash and temperatures greater than 800°C gives crystalline ash (Prasad, 2000), (Bouzoubaâ & Fournier, 2001), (Maeda, 2001).

Mehta suggested that maintaining the combustion temperature below 500°C under oxidising conditions for prolonged periods, or up to 680°C with a hold time less than 1 min, could produce amorphous silica. Thermal analysis has shown that furnace temperature of approximately 650°C can produce amorphous silica (Mehta, 1979.) RHA is often incinerated between 650°C and 800°C.

2.4.7.3 Fineness of RHA

Generally, reactivity is favored by increasing the fineness of the reacting materials. but, reactivity of RHA is attributed to its high content of amorphous silica and its porous nature (Boeteng, 1990). RHA being porous in nature has an extremely high surface area while its average size still remains fairly high. Compared to silica fume with average particle size of 0.1 μm, RHA with particle size around 45 μm has three times higher surface area. Since RHA derives its pozzolanicity from its internal surface area, grinding of RHA to a high degree of fineness should be avoided (Mehta, 1979.) Bui et al (2005) also stated that at a certain stage of grinding the RHA, the porous structure of particles would collapse, resulting in reduced surface area. Bouzoubaa & Fournier (2001) concluded that the optimum grinding time of RHA was 140 sec when it was ground in a pulveriser. Other studies show that RHA ground in ball mill for a period of 15 min to 30 min resulted in particle sizes around 45 μm (Chandrasekar, 2003).

RHA is thrice as fine as silica fumes and is thus more effective in closing the voids and giving high strength and durability when mixed with ordinary Portland cement to produce SCC.

2.4.7.4 Properties of SCC containing RHA

SCC with a similar water cement ratio will usually have a slightly higher strength compared with traditional vibrated concrete, due to the lack of vibration giving an improved interface between the aggregate and hardened paste. The strength development will be similar so maturity testing will be an effective way to control the strength development whether accelerated heating is used or not (EFNARC, 2002). The tensile strength may be safely assumed to be the same as the one for a normal concrete as the volume of paste (cement + fines + water) has no significant effect on tensile strength. Increasing the paste volume could decrease the E value because SCC often has higher paste content than traditional vibrated concrete. Some differences can be expected and the E-value may be somewhat lower (Ozawa, 1995).

RHA has been used as a highly reactive pozzolanic material to improve the microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in self compacting concrete. Mechanical experiments of RHA blended portland cement concretes revealed that in addition to the pozzolanic reactivity of RHA (chemical aspect), the particle grading (physical aspect) of cement and RHA mixtures also exerted significant influences on the blending efficiency. The scope of this research was to determine the usefulness of RHA in the development of economical self compacting concrete. The cost of materials will be decreased by reducing the cement content by using waste material like rice husk ash.(Ahmadi, 2007) presented a study on the development of mechanical properties up to 180 days of self compacting and ordinary concretes with rice-husk ash, from a rice paddy milling industry in Rasht (Iran). Two different replacement percentages of cement by RHA, 10%, and 20%, and two different water/cementitious material ratios (0.40 and 0.35), were used for both self compacting and normal concrete specimens. They found that RHA provides a positive effect on the mechanical properties after 60 days. They also observed that self compacting concrete specimens have higher value than normal concrete specimens in all tests except modulus of elasticity. Also, specimens with 20% replacement of cement and RHA mixtures also exerted significant influences on the blending efficiency. In general, the mechanical properties concrete improve when we replace RHA with the cement.

2.4.7.5 Advantages of using RHA with SC

Rice husk ash should be maintained uniformly. The temperature ranges and the corresponding incineration duration are in a wide range. obviously, the pozzolanicity index of the ash should also differ considerably, in spite of obtaining amorphous state. This has not yet been fully established. Instead of taking amorphous state, if the pozzolanicity of ash is set as the criterion then the temperature and duration ranges may be narrowed down.

Additionally, grinding medium and grinding time may be conveniently adopted as RHA is highly fragile and porous. RHA performs better than other pozzolans in general and silica fume in particular. In the year 2002, India produced 123 Mt of paddy. That is, the ash production out of this paddy should be about 5 Mt/year.

Today, Indian cement production is about 105 Mt/annum. Keeping in view environmental considerations, energy conservation and economy, reactive ash production can lead to excellent technological benefits useful to the community at large.

2.4.7.6 Applications of RHA

Due to its refractory properties, crystalline RHA is most wanted in steel industries, ceramic industry and for the manufacture of refractory bricks (Confidential Report, http:// www.dti.gov.uk, 2003);(Prasad, 2000). Some other general uses are listed as follows:

1. Basha et al. (2005) examined the possibilities of improving residual soil properties by mixing RHA and cement in suitable proportions as stabilizing agents.
2. Indian Space Research Organization has successfully developed a technology for producing high purity silica from RHA that can be used in silicon chip manufacture (Confidential Report, http:// www.dti.gov.uk, 2003).
3. Naito (1999) introduced a low cost technology for controlling insect pests in soya beans by using RHA.
4. Saha et al. (2001) studied the possibility of using RHA in water purification.
5. Attempts have been made to utilize RHA in vulcanizing rubber (Siriwandena, 2001)
6. Rice husk burnt for prolonged periods have been successfully used as oil absorbent.

2.4.8 Fly Ash

Fly ash is the finely divided residue that results from the combustion of ground or powdered coal (Chi, 2003). It is composed of siliceous and aluminous ingredients and possesses limited cementitious properties unless so finely divided that its fineness is at least equal to or less than the fineness of the cement with which it is mixed. In the presence of water in mix, it reacts with calcium hydroxide at ordinary temperature and thereby forms compounds that have high cementitious qualities (E. G. Nawy, . 1997)

Fly ash is divided into two classes: Class-F and Class-C. Class-F fly ash is normally produced from burning of anthracite or bituminous coal and has pozzolanic properties but little or no cementitious properties. Class-C fly ash is normally produced from burning of lignite or sub-bituminous coal and has some autogenously cementitious properties (Wang, 2006). However, most fly ashes that are being used in concrete production are Class-F. The use of fly ash influences compressive strength, workability, heat of hydration, sulfate resistance, permeability and alkali-silica reaction of concrete (Ellis, 1992).

The replacement of cement by fly ash in producing concrete is possible up to 50%. However, many concretes containing Class-C fly ash in the range of 20 % to 40 % of the total cementitious material show equivalent or higher strength than concretes containing Portland cement only (Ellis, 1992).The replacement between 30 % and 50 % by weight of cement gives better results. Thus, use of fly ash is highly desirable for an increase in strength of concrete.

2.4.9 Ground Granulated Blast-Furnace Slag (GGBS)

Ground granulated blast furnace slag (GGBS) is a waste product in the manufacture of pig iron, about 300 kg of slag being produced for each tone of pig iron. When this slag is rapidly quenched and ground, it will possess latent cementatious properties. After processing, the material is known as GGBS whose hydraulic properties may vary and can be separated into grades. Slag can be interground with cement or used as additional cement at the batching facility. Fineness of GGBS is usually greater than 350 m^2/kg and occasionally in excess of 500 m^2/kg specific gravity (Neville, 1995). The possible beneficial effects of incorporating GGBS in the mix are improved workability, lower peak temperature, denser microstructure, reduced water permeability (about 100 times lower), reduced chloride ion diffusivity (about 10 times lower), reduced risk of alkali-silica reaction and sulfate attack and improved long-term strength and durability performance.

Slag modifies the flocculation of cement, with a resulting reduction in the water demand. It reduces bleeding but leads to retardation at normal temperature, typically 30-60 minutes. The reactivity of GGBS at higher temperature is considerably increased. Steam curing of concrete containing GGBS can therefore be used. Prolonged moist curing of concrete containing GGBS is particularly important. Very good development of strength of concrete containing 50-75% of GGBS, with a total content of cementations material between 300-420 kg / m^3 has been reported. In view of the advantageous properties of GGBS, especially of improving workability and permeability of concrete, it has been utilized in this work.

2.4.10 Water reducing admixtures

The use of super plasticizers in concrete manufacture was a milestone in the history of concrete, and this played a central role in the development of high strength and performance concrete. Super plasticizers are admixtures, which are added to concrete mixture in very small dosages. Their addition results in significant increase of the workability of the mixture, in reduction of water/cement ratio or even of cement quantity. Their performance depends on the type of the super plasticizer, the composition of the concrete mixture, the time of addition and the temperature conditions during mixing and concreting (Papayianni, 2005)

Water reducing admixtures are chemicals that increase workability of concrete and allow reduction of water. Super plasticizers or high range water reducers differ from conventional water reducers in that they are capable of reducing the water requirement by up to 30%. They can also increase the slump by up to 250 mm (Mehta, 1986). More significant than the increase in workability is the fact that concrete having lower w/c ratios can be used. Theoretically, a w/c ratio of 0.27 is adequate for hydration and any water greater than this ratio lowers the potential compressive strength that can be achieved. It has also been observed that concrete containing super plasticizers have high ultimate strengths, excellent durability and water proofing characteristics.

The percentage of water in the concrete can be reduced by additives such as superplasticizers and admixtures, while also improving strength, workability and water proofing characteristics. The superplasticizer used in this work is intended to give good viscosity to the framework.

The amounts of superplasticizer determined in mortar mixtures relates satisfactorily with the admixture dosage necessary for production of SCC the amount of admixture needed for production of concrete is almost constant when the superplasticizer content is related to the mass of cement rather than mass of powder ratio.

In general, mixtures with higher w/c demand higher volumes of filler, which are necessary for mixture stabilization, while higher amounts of superplasticizer promote the necessary self-compatibility properties (Konsta, 2006) superplasticizers also increase the fluidity at early age without affecting the setting and hardening behavior of concrete. For that purpose, different polymers are used. Whereas polynaphtalene sulfonates (PNS) are often reported to act on cement particles dispersion by electrostatic repulsion. Polycarboxylate with polyoxyethylene graft chains (PCP) or diphosphonate terminated nonfunctional polyoxyethylene polymers are given to disperse cement particles because of the steric hindrance effect resulting from the extension of their graft chains away from the surface of cement particles(Uchikawa, 1995) ,(Uchikawa, 1997)

Moreover, it has been reported that the type of superplasticizer (SP) and the mixing method and preparation conditions or the surrounding environment of concrete could significantly affect the fluidity of the paste (Tagnit-Hamou, 1993),(Jolicoeur, 1997).

There is more room for improvement for admixtures such as superplasticizer suitable for self-compacting concrete. In order to achieve this purpose, characterization of materials is indispensable. The requirements for superplasticizer in self-compacting concrete are summarized below.

(1)High dispersing effect for low water/powder (cement) ratio: less than approx.100% by volume.

(2) Maintenance of the dispersing effect for at least two hours after mixing.

(3) Less sensitivity to temperature changes.

There have been many examples of the development of new type of superplasticizer for self-compacting concrete. Characterization of the dispersing effect of superplasticizer is dependent on the effect of water flow.

2.5 Mix-design

Self-compactability can be largely affected by the characteristics of materials and the mix-proportion. A rational mix-design method for SCC using a variety of materials is necessary (Okamura, 1995). Two main approaches for the mix-design of SCC are described.

2.5. 1 Japanese concept for design of SCC

The Japanese concept for design of SCC is based on a method proposed by (Okamura, 1995). The authors have proposed a simple mix-proportioning system assuming general supply from ready-mixed concrete plants. The coarse and fine aggregate contents are fixed so that self-compactability can be achieved easily by adjusting the water to powder volume ratio and superplasticizer dosage only. The mixed design proposed is:

- Coarse aggregate content is fixed at 50% of the solid volume.
- Fine aggregate content is fixed at 40% of the mortar volume.
- Water-powder ratio in volume is assumed as 0.9 to 1.0 depending on the properties of the powder.
- Superplasticizer dosage and the final water-powder ratio are determined so as to ensure the self compactability.

The value of water to powder volume ratio (Vw/Vb) is optimized by mortar flow test and mortar funnel test. (Takada, 1999) considered the slump flow value of 650±30 mm and the V-funnel time of 11±2 s as adequate for the workable SCC. To increase the viscosity and thereby reduce the deformity, an organic stabilizer (welan gum) was used. In organic stabilizer, there is a polymer formation of 3-dimensional framework which increases the viscosity and water adsorption.

2.5.2 German concept for design of SCC

A new concept for mix design is developed in a precast plant of HOCHTIEF of Germany (Surlekar, 2002). A new type of SCC was developed by maintaining the content of ultra fine powder within the cod limitations of German standards. Though the ultra fine content in this SCC are within the limits specified by DIN 1045, flowability is very high and beyond the limits laid down in consistency classes of the DIN standard, thereby demonstrating this concrete as SCC. In this mix, newly developed additives based on polyacrylate and multicarboxylatether (MCE) are used. The product is synthesized so that saponification is sterically hindered by long lasting action

Complete dispersion is achieved at a low dosage through a 3-dimensional configuration of long chain. The hydration of cement is unaffected because of low contact area of polymer

2.5.3 Diagnosis for mix performance adjustment

Field and laboratory mixtures may require adjustment from time to time to compensate for some unintentional change in the characteristics. Adjustment may be required, for example, to compensate for a change in moisture content of the aggregates; it may be desired to proportion a mixture for greater or lesser cement content, or use of chemical admixtures; or other cementitious material, or perhaps, a change in slump or air content may be necessary. Guidelines have been proposed for mix proportioning adjustment (Mehta 1986). However, accurate determination of the amount of ingredients required for the desired adjustment largely depends on the proper judgment on the part of the experimenter or concrete producer in relation to the properties of concrete. Mix proportioning of self compacting concrete is very complicated compared to normal concrete. Several remedial measures have been proposed to improve the performance of concrete when the desired response is not achieved. Observation and experience with particular materials should be used whenever possible. These diagnostic aids can be found in literatures such as journals, textbooks and codes of practice. The following were proposed by Aïtcin (1998):

1. If the desired compressive strength is not obtained and the fracture surface shows a number of intergranular fractures, the aggregate can be blamed and a stronger aggregate is recommended.

2. If the fracture surface shows considerable debonding between the coarse aggregate and the hydrated cement paste, the coarse aggregate used has too smooth a surface or is

simply too dirty, and therefore a coarse aggregate with a rougher or cleaner surface must be used.

3. If the fracture surface passes almost entirely through the hydrated cement paste around the aggregates, a stronger concrete can be made with the same aggregates by lowering the water/binder ratio.

4. If the compressive strength does not increase when the water/binder ratio decreases, the aggregate strength or cement/aggregate bonding controls the failure rather than the water/binder ratio. So, a stronger concrete may be possible using the same cement but a stronger aggregate.

5. If the concrete does not have the desired slump, the super plasticizer dosage is not high enough and must be increased, or else the water dosage has to be increased as well as the cement content in order to keep the same water/binder ratio.

6. If the concrete experiences a rapid slump loss, the cement is perhaps more reactive than expected and the water dosage has to be increased, or the super plasticizer is particularly inefficient with the selected cement, so its dosage has to be increased or another brand of super plasticizer has to be used.

7. If workability is inadequate, a poor shape or gradation of the coarse aggregate, or the incompatibility of the particular cement-super plasticizer combination can be blamed. In the first case, the amount of coarse aggregate has to be decreased, and in the second case, either the cement or the super plasticizer or both should be changed.

8. If the density of concrete is very high, reduce the cement content and add water. Also reduce the fine aggregate content and add coarse aggregate, then reduce both cement and water.

9. If the density of concrete is very low, increase the cement content and reduce the fine aggregate content. Also, reduce the coarse aggregate content and increase the fine

aggregate, cement and water. The procedure outlined for mixture proportioning adjustment by ACI Committee 211.2-1998 varies depending on the method of mix design; that is either the weight or volume method (ACI, 1998).

2.5.4 Mixing equipment and trial mixes

Self-compacting concrete can be produced with any efficient concrete mixer including paddle mixers, free fall mixers and truck mixers, but force action mixers are generally preferred. However, with SCC it is particularly important that the mixer is in a good mechanical condition and that it can ensure full and uniform mixing of the solid materials with sufficient shear action to disperse and activate the superplasticiser.

Experience has shown that the time necessary to achieve complete mixing of SCC may be longer than for normal concrete due to reduced frictional forces and to fully activate the superplasticiser. It is important that preliminary trials are carried out to ascertain the efficiency of individual mixers and the optimum sequence for addition of constituents. The volume of concrete for preliminary full-scale trials should not be less than half the capacity of the mixer. Prior to commencing supply it is recommended that plant trials be conducted to ensure that in full scale production, the mix still conforms to the specifications for both fresh and hardened properties.

2.5.5 Vibration

Vibration of SCC should generally be avoided as it is likely to result in significant settlement of the coarse aggregate. If the desired compaction is not being achieved, the concrete should first be checked for conformity to the specification. If it is in conformity but full compaction is not being achieved, consider changing the Specification.

There are some occasions when carefully controlled and light vibration may be needed:

- In some structures the formwork shape may cause air to be trapped at certain locations. This can normally be removed by localized tapping or simple rodding in the affected area.
- Slabs, especially those cast from SCC in the lower slump-flow class may require light tamping or a very gently vibrating screed bar to give a level finish, free of protruding coarse aggregate.
- Following a break in placing, if the live surface has crusted or stiffened to the extent that a cold joint or surface blemish could form (ERMCO, 2005)

2.6 Mixing approach

In order to improve the quality of recycled aggregate concrete, a two–stage mixing approach (TSMA) was developed by (Tam, 2005) which divides the mixing process into two parts and proportionally splits the required water into two parts which are added after mixing one part with fine and coarse aggregate and cement, while the normal mixing approach only puts all the ingredients of concrete and mixes them. Improvement of strength can be achieved up to 21.19% for 20% of RA under 28-day curing condition using TSMA.

To avert the absorption of water by the aggregates before the completion of the rehydration of the cement and to obtain a homogeneous mixture, the process of mixing is done in two stages: the first is to put all the aggregates with 20% of the water designed for mixing to coat the particle aggregates, which leads to reduce the absorption of aggregates of water. In the second stage, the remaining water is added to the cement and then the rest of the additives are given enough time to mix with it. This is what has been done in this study.

2.7Test method and workability properties of SCC

The water demand of lightweight concrete is affected by the surface texture and shape of the aggregate particles. The rheological behavior of lightweight concrete is different from normal weight concrete. Specifically, at the same slump, lightweight concrete exhibits better workability. The Workability of SCCs was evaluated by slump flow diameter and time, V-funnel flow time, L-box height ratio, U-Box height difference and J-Ring flow diameter tests. Furthermore, compressive strength, splitting tensile strength, ultrasonic pulse velocity, elasticity modulus of SCCs were measured at hardened state at 7, 28 and 90 days. Results showed that using MC, LLFA and GBFS positively affected the flowability, passing ability and viscosity of SCCs.(Ahmet Beycio lua, 2014)

The workability of mixes containing angular aggregate can be considerably improved by the inclusion of entrained air in the mix this reduces the water demand and consequently reduces the tendency of bleeding and segregation. Partial replacement of lightweight fine aggregate by normal weight fine aggregate makes placing and compaction of concrete easier.

With regards to development to characterize the properties of SCC, no single method has been found until date, which characterizes all the relevant workability aspects, and hence, each mix has been tested by more than one test method for the different workability parameters. Table 2.3 gives the recommended values for different tests given by different researchers for a mix to be characterized as an SCC mix (Aggarwal, 2008). SCC is characterized by filling ability, passing ability and resistance to segregation

Table2.4: Recommended limits for different workability properties.

Sr. No.	Property	Range
1	Slump Flow Diameter	500-700 mm [7]
2	T_{50cm}	2-5 sec [7]
3	V-funnel	6-12 sec [8]
4	L-Box H2/H1	≥ 0.8 [9]

2.7.1 Slump test

The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions. On lifting the slump cone, filled with concrete, the concrete flows. The average diameter of the concrete circle is a measure for the filling ability of the concrete. The time T_{50cm} is a secondary indication of flow. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reaches diameter of 500mm (Aggarwal, 2008)

Figure 2.4: Slump flow test

2.7.2 V-funnel test

The flowability of the fresh concrete can be tested with the V-funnel test, whereby the flow time is measured, as is shown in Figure 2.5.The funnel is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus is measured. Further, T_{5min} is also measured with V-funnel, which indicates the tendency for segregation, wherein the funnel can be refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation, the flow time will increase significantly. according to (K. Khayat & Manai, 1996), a funnel test flow time less than 6s is recommended for a concrete to qualify for an SCC.

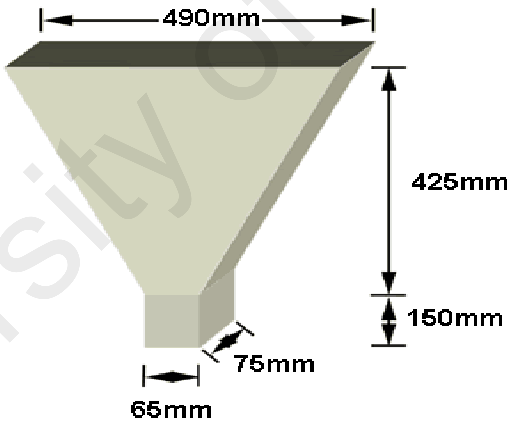

Figure 2.5: V-funnel tests.

2.7.3 L- Box test

The passing ability is determined using the L- box test (Petersson, 1996) as shown in Fig 2.6. The vertical section of the L-Box is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. The height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H2/H1). This is an indication of passing ability.

The specified requisite is the ratio between the heights of the concrete at each end or blocking ratio to be ≥ 0.

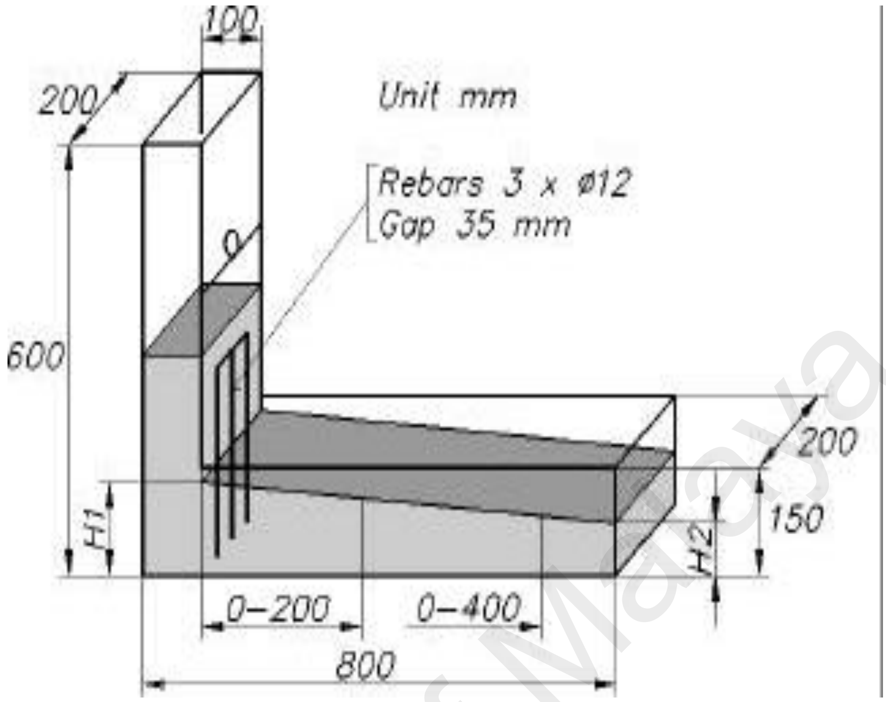

Figure 2.6: L-Box test

2.7.4 J-Ring test

The principle of the J-Ring test may be Japanese, but no references are known. The J-Ring test itself has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations

3x the maximum aggregate size might be appropriate The diameter of the ring of vertical bars is 300mm, and the height 100 mm

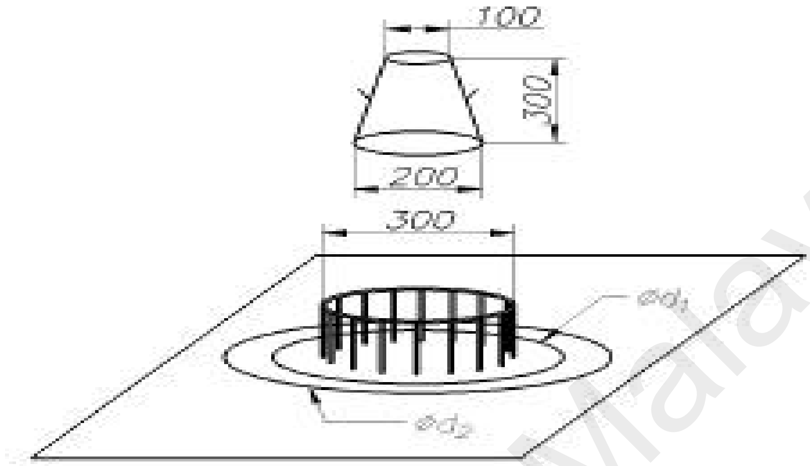

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Figure 2.7: J- Ring used in conjunction with the slump flow

2.7.5 Sieve segregation resistance test

It has been found that it is possible to manufacture self-compacting concrete with constant quality, especially self compactability. However; any variation in material characteristics can affect self-compactability. The most influential variant is the water content of fine aggregate, which results in variations in the water content of the concrete itself. To solve this problem, some general construction companies employ segregation-inhibiting agent. This type of agent is effective in making self-compactability less sensitive to the variation of the water content in the concrete. Various agents are available for this purpose in Japan(Hibino, 1998).

Congested segregation resistance plays an important role for SCC because poor segregation resistance would cause poor deformability, blockage around reinforcement and non-homogeneous properties of the hardened concrete (K. Khayat, 1999). In order to increase the segregation resistance of

SCC, high powder (i.e. limestone powder, fly ash) content is normally required.

alternatively, a viscosity agent is often employed to ensure a high resistance to segregation (K. H. Khayat & Guizani, 1997)

So, a high percentage of water used in cement or a small percentage of fine aggregate can lead to the issue of segregation. In this study, this issue is addressed by using some chemical additives to maintain the basis of the mixtures in the SCC.

Figure 2.8: Segregation test method

2.8 Mechanical properties of hardened SCC.

The basic ingredients used in SCC mixes are practically the same as those used in the conventional HPC vibrated concrete, except they are mixed in different proportions and the addition of special admixtures to meet the project specifications for SCC. The hardened properties are expected to be similar to those obtainable with HPC. Laboratory and field tests have demonstrated that the SCC hardened properties are indeed similar to those of HPC. Table 2.5 shows some of the structural properties of SCC (Oucho, 2003).

Table2.5: Structural properties of SCC

Items	**SCC**
Water-binder ratio (%)	25 to 40
Air content (%)	4.5-6.0
Compressive strength (age: 28 days) (MPa)	40 to 80
Compressive strength (age: 91 days) (MPa)	55 to 100
Splitting tensile strength (age:28 days) (MPa)	2.4 to 4.8
Elastic modulus (GPa)	30 to 36
Shrinkage strain (x 10^{-6})	600 to 800

2.8.1 Compressive strength

Higher compressive strength requires very high cement contents. As in normal concrete, silica fume improves the strength development of lightweight concrete. Other cementations materials can also be incorporated in lightweight concrete (Yeh, 2007).

However, mixes containing rice husk ash indicate lower compressive strength until 60 days rather than samples with no replacement, but by increasing the rate of pozzolanic reactions of rice husk ash in the matrix, strength of composite mixes goes up. Also, increasing the amount of rice husk ash replacement in matrix shows a greater effect on strength of normal concrete than SCC mixes. The mixes containing 20% rice husk ash have the highest compressive strength than the others. In addition, water to binder ratio has more impact on normal concrete rather than on self-compact concrete. Moreover, by increasing the amount of replacement, water to binder ratio rises (Ahmadi, 2007).

From 28 days onward, all pozzolanic mixtures under water curing have been shown to exhibit strength enhancement (Mahmud, 2009). Comparing the strength development of RHA and CSF concrete cured in water, it is clear that partially replacing cement with RHA improves the strength of concrete at 28 days and that RHA contributes to the strength development as early as 3 days, similar to that reported earlier(Mahmud, 2005).

When different sources of US fly ashes were used at replacement levels of 58%, higher strengths were obtained for a variety of fly ash chemistries than those measured in the work by (Bilodeau et al. 1994), who used 50% fly ash concrete. They used a significantly lower water/cementitious material ratio of 0.33 versus 0.40, although the total cementitious content was somewhat lower (362 kg/m3 versus 390.8 kg/m3).

Inclusion of 50% blast furnace slag in the natural aggregate mixes was beneficial, giving the highest strength at 28 and 84 days of all the mixes studied with values of 45.7 and 49.8 MPa, respectively. Blending 25% fly ash and 25% slag resulted in improved strengths at all ages compared with the 50% fly ash mix, particularly at 84 days. Increasing the cement replacement level to 70% slag resulted in slightly reduced strength compared with concrete containing 50% slag. The maximum mean strength difference was 2.7 MPa at 7 days. The results demonstrate that 40 MPa compressive strength can be readily achieved at 28 days with a mix design containing 50 or 70% slag as partial replacement of cement and that long term strength under wet curing conditions can also be achieved with mixes containing 25% fly ash/25% slag (Berndt, 2009).

In 30 MPa concretes even at 70% replacement, the strength gain rate of SCC was almost similar to that of normal concrete. At the 70% replacement level, both the self compacting fly ash concretes obtained their designed target strength of 30 MPa at 28 days and both were performing similarly. However, at 180 days, the strengths obtained for SCCs were greater than the normal vibrated concrete. The strength development of normal vibrated concrete almost came to a complete stop after 90 days, whereas the SCCs continued to gain strength even after 90 days in 60 MPa grade concrete, both the self compacting fly ash concretes achieved their design strengths at 90 days. Normal concrete had shown slightly higher strengths at all ages. At 180 days, the strengths of both normal vibrated concrete and SCCs were comparable. In the case of high strength normal vibrated self compacting fly ash concretes of 90 MPa and 100

MPa, it was noticed that the normal vibrated concretes, even at 180 days, did not achieve their design strengths and the strength gain rate was comparatively low after 28 days for 90 MPa concrete whereas it was low from 7 days in case of 100 MPa concrete.

But in the case of self compacting fly ash concretes the results indicate that there was continuous and significant improvement in strength beyond the age of 28 days. It was also observed that both the self compacting fly ash concretes designed for 90 and 100 MPa achieved their design strengths at 180 days (Dinakar, Babu, & Santhanam, 2008) Thus, to improve and develop the compressive when using self compacting concrete, we should be to determine the initial ratios appropriate for the strength required.

2.8.2 Flexural strength

Flexural strength increases by increasing the amount of replacement.Increase is grater in normal concrete than SCC. In addition, by increasing the amount of replacement in self compact concrete, effect of water to binder ratio is more considerable than normal concrete. Increasing the amount of replacement leads to increase in the water to binder ratio (Ahmadi, 2007).

By increasing the rate of pozzolanic reactions of rice husk ash in the matrix, strength of composite mixes goes up. Also, the mixes containing 20% rice husk ash have the highest flexural strength.

2.8.3 Tensile splitting strengths

The value of tensile strength is important for non reinforced concrete structure such as pavement slabs and airfield runways. These structures are designed based on bending strength rather than compressive strength(Zain, 2002). Splitting tensile development occurs up to the age of 360 days . From 28 days onwards, pozzolanic mixtures under water curing exhibit strength enhancement compared with control concrete.

2.8. 4 Modulus of elasticity test

The modulus of elasticity like compressive and flexural strength increases. Normal concrete mixes show a modulus of elasticity around 9% to 17% more than those of SCC. Also, by increasing the amount of rice husk ash in the matrix, modulus of elasticity of all mixes is reduced. It has been shown that water to binder ration has no impact on modulus of elasticity in all cases (Ahmadi, 2007). In this work, the modulus elasticity is improved by adding different percentages of admixtures materials such as RHA, FA and GGBS.

2.8.5 Poisson ratio

Poisson's ratio (ν), named after Siméon Poisson, is the ratio, when a sample object is to the applied load), stretched, of the contraction or transverse strain (perpendicular to the extension or axial strain (in the direction of the applied load). The Poisson's ratio of a stable, isotropic, linear elastic material cannot be less than −1.0 nor greater than 0.5 due to the requirement that Young's modulus, the shear modulus and bulk modulus have positive values (Gercek, 2007).

Most materials have Poisson's ratio values ranging between 0.0 and 0.5. A perfectly incompressible material deformed elastically at small strains would have a Poisson's ratio of exactly 0.5. Most steels and rigid polymers when used within their design limits(before yield) exhibit values of about 0.3, increasing to 0.5 for post-yield deformation (which occurs largely at constant volume.) Rubber has a Poisson ratio of nearly 0.5. Cork's Poisson ratio is close to 0: showing very little lateral expansion when compressed. Some materials, mostly polymer foams, have a negative Poisson's ratio; if these materials are stretched in one direction, they become thicker in perpendicular directions. Some anisotropic materials have one or more Poisson ratios above 0.5 in some directions. Assuming that the material is stretched or compressed along the axial direction (the *x* axis in the diagram), the Poissons' ratio can be expressed as shown in Eq. (2.1):

$$\nu = -\frac{d\varepsilon_{\mathrm{trans}}}{d\varepsilon_{\mathrm{axial}}} = -\frac{d\varepsilon_{\mathrm{y}}}{d\varepsilon_{\mathrm{x}}} = -\frac{d\varepsilon_{\mathrm{z}}}{d\varepsilon_{\mathrm{x}}} \qquad (2.1)$$

Where ν is the resulting Poisson's ratio,

$\varepsilon_{\mathrm{trans}}$ is transverse strain (negative for axial tension (stretching), positive for axial compression)

$\varepsilon_{\mathrm{axial}}$ is axial strain (positive for axial tension, negative for axial compression).

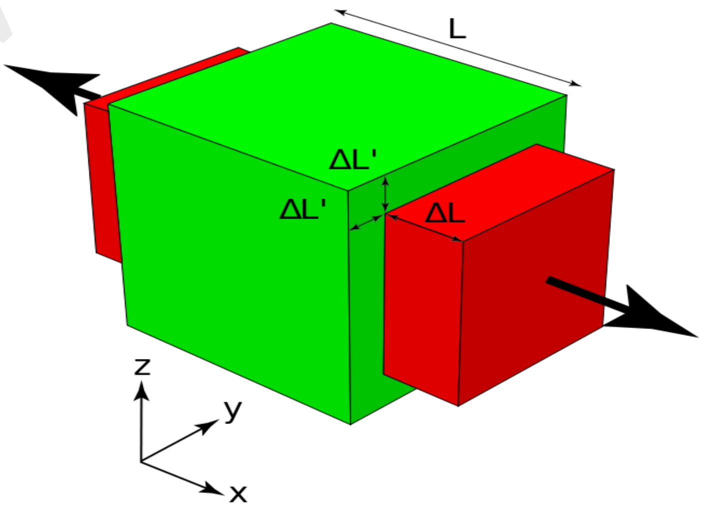

Figure 2.9: The process of change in the longitudinal and transverse material

A cube with sides of length L of an isotropic linearly elastic material subject to tension along the x axis, with a Poisson's ratio of 0.5 is shown in Fig.2.9. The green cube is unstrained, the red is expanded in the x direction by ΔL due to tension, and contracted in the y and z directions by ΔL'.

2.8.6 Effect of curing on mechanical properties

These can dry quickly because of the increased quantity of paste, the low water / binder ratio and the lack of bleed water at the surface. Initial curing should therefore commence as soon as possible after placing and finishing, in order minimize the risk of surface crusting and shrinkage cracks caused by early age.

2.9 Time dependent tests

One of the reasons for the use of self-compacting concrete (SCC) is to improve the durability of concrete structures. However, autogeneous and drying shrinkage of SCC may be large because SCC contains a large amount of cement and filler. Seven types of SCC were made with a w/c ratio of 0.55 and different slag contents. The results show that replacing sand by GBFS gives rise to mixes with higher pore volume but with slightly finer porous structure (smaller median pore and threshold diameters). At early ages slag SCCs have similar compressive strength to that of the reference concrete, although in the long term their strength increases as a result of slag reactivity(M. Valcuendea, 2015)

:

Im a study conducted at Kochi University of Technology Standard Specifications for Concrete Structure (JSCE 2002) design code to calculate shrinkage and specific creep for the case of volume to surface ratio. Specific creep of SCC with higher powder content showed higher specific creep, but for the case of SCC which was made by adding limestone powder content to conventional concrete, almost the same specific creep as that of the conventional concrete was seen. It was also observed that limestone

Powder ratio did not significantly affect shrinkage. The shrinkage model which considers absolute water content as the main parameter was shown to be applicable to SCC using limestone powder.

2.9.1 Expansion and drying shrinkage test at SCC

Early-age shrinkage measurements provide a challenge due to the difficulty in making accurate measurements of the concrete prior to demolding. The shrinkage must be measured immediately after casting in a mold which permits constant reading without disturbing the concrete. Early-age shrinkage is associated with autogenous phenomena (Lura & 2003),(Bentz & Jensen, 2004),(Holt, 2005),(Bentur & Kovler, 2003).

Autogenous shrinkage of cement paste and concrete is defined as the macroscopic volume change occurring when there is no moisture exchange between the material and the exterior surrounding environment. It is the result of chemical shrinkage produced by the hydration of cement particles(Aïtcin, 2003). Autogenously shrinkage has only recently been documented and accurately measured. In the tests, the concrete sample is sealed, there is no moisture transfer to the surrounding environment, and the shrinkage can be measured by volumetric or linear measurements. (Jensen & Hansen ,1995) developed a special, corrugated mould system, which combines the advantages of linear and volumetric measurement. Before set, the corrugated mould system transforms the volumetric deformation into a linear deformation, and, after set, a normal, linear deformation is measured. In this way, it is possible to commence linear measurements immediately after casting. In conventional concretes, autogenous deformation is generally negligible, whereas in HS/HPC it can be considerable(Jensen & Hansen, 2001),(Hammer, 2002),(Barcelo et al., 1999),(Boivin, 2001).

Previous researches have shown that POFA has a high SiO_2 content, and it has recently been accepted as a pozzolanic material(Adepegba, 1989),(Tangchirapat, 2007) even so, the durability properties (i.e., water permeability and drying shrinkage) of concrete containing POFA have not been thoroughly investigated.

Drying shrinkage, one of the main causes of cracks that directly affect the strength and durability of concrete, usually occurs in hot and dry environments due to the loss of internal water in the concrete to the environment. This results in the reduction of concrete volume and leads to crack formation in hardened concrete. Furthermore, most of this drying shrinkage cannot be regained by rewetting the concrete.

2.10 Durability tests of SCC

SCC can be deteriorated by abrasion and freeze-thaw cycles. It can be attacked by strong acid, chloride ions, sulfate ions, or other types of aggressive chemicals. It can also be attacked by a gas or even by bacteria. Moreover, it can be self-destructive in the presence of reactive aggregates.

The following sections briefly highlight the major durability issues of SCC. The durability performance of SCC is closely related to several concrete properties. The following sections briefly discuss the effects of porosity, sulphate attacks, air content and resistance chloride penetration test RCPT.

2.10.1 Porosity

The porosity of concrete is mainly comprised of capillary and gel pores, and pore channels connecting the pores. The capillary pores and their connectivity constitute the permeable porosity of concrete. The volume, size and continuity of capillary pores have considerable effects on the transport properties and hence on the durability of concrete (Malhotra, 1992) porosity also affects the electrical resistance, and thus the corrosion resistivity of concrete(Moranville, 1992). The pore system in SCC is more refined than that in normal concrete (Nagai, 1999).

The average pore diameter is lower in SCC. This is mainly because of a low water-binder ratio. The higher degree of packing due to good consolidation, the greater degree of hydration due to deflocculation and dispersion of cement particles in presence of high-range water reducer, and the pozzolanic and micro-filling effects of mineral admixtures also contribute to form a refined pore structure in SCC. The refined pore structure greatly improves the transport properties of concrete, and therefore the durability of SCC.

2.10.2 Air content

A sufficient amount of air voids must be present in concrete to protect it from freeze-thaw damage. It has been found that SCC incorporating adequate air voids.

performs very well in a freeze-thaw environment(Brameshuber, 2003),(Hayakawa, 1994)However, the air voids must be stable to ensure the freeze-thaw durability of concrete. The air-void stability can be secured in SCC with high binder content, low water-binder ratio and high sand aggregate ratio, and by incorporating a viscosity modifying admixture (K. H. Khayat & Assaad, 2002).

2.10.3 Resistance of sulphate attack

The external attack of sulphate salts is considered one of the major problems affecting concrete durability. Sulphate is highly soluble salts in the form of sodium sulphate (Na_2SO_4), calcium sulphate ($CaSO_4$), potassium sulphate (K_2SO_4), and Magnesium sulphate ($MgSO_4$).

Sulphate attack is the process in which sulphate react with various phases of hydrated cement paste leading to the deterioration of concrete matrix through spalling, softening, and mass loss, and it may lead to expansion and loss in strength and elasticity. It is a complex process because of the numerous controlling factors (Shehata, 2008), (Wee, 2000).

When concrete is attacked by the magnesium sulphate (MS) solution, + 4 SO ions react with cement hydration products to form ettringite ($C_3A{\cdot}3CS{\cdot}H_{32}$) and gypsum ($CaSO_4{\cdot}2H_2O$). In addition to that, MS has the most damaging effect. Since Mg+ and Ca+ ions associate well, MS can react with the calcium silicate hydrate gel and form magnesium silicate hydrate, which is non-cementitious (Cohen, 1988). This fact has been recognized for a long time, albeit significant controversy exists in recognizing the effect of each of these products in the deterioration of concrete (Santhanam et al, 2001).

It has been reported that the addition of mineral admixtures to concrete would enhance its resistance to sulphate attack (Wee, 2000). One of the most promising mineral admixtures is the rice husk ash (RHA). Rice husk is an agricultural residue from the rice milling process. RHA has not been utilized yet in the construction industry with the exception of repair works at the Bowman Dam in northern California’s Sierra Nevada Mountains, US, where it was used with positive results in a dry-mix

(Talend, 1997). Sulfate attack is consider one of the major deteriorative problems occurred when the cement based materials, such as concrete, mortars and buildings, are exposed to this environment. Sulphate ions in soil, ground water and sea water may cause deterioration of reinforced concrete structures by provoking expansion and cracking due to factors such as type of cement, sulphate cation type, sulphate concentration and the period of exposure. Many structures affected by sulphate degradation often need to be repaired or, in most severe cases, they need to be reconstructed (Neville, 1995) .

The reason for not utilizing this material is probably due to the lack of understanding the characteristics of the RHA blended concrete. Many researchers have already published articles about the properties of the blended RHA concrete such as strength and durability. However, only limited research was found on the effect of RHA on concrete resistance to sulphate attack. In this study, the concrete resistance to sulphate attack is improved by using fly ash FA, rice husk ash RHA and GGBS in ratios 15%, 10% and 5%, respectively with SCC concrete.

2.10.4 Rapid chloride penetration (RCP)

The rate of ingress of chlorides into concrete depends on the pore structure of the concrete, which is affected by factors including materials, construction practices, and age. The penetrability of concrete is obviously related to the pore structure of the cement paste matrix. This will be influenced by the water-cement ratio of the concrete, the inclusion of supplementary cementing materials which serve to subdivide the pore structure (McGrath, 1997) and the degree of hydration of the concrete. The older the concrete, the greater amount of hydration that has occurred and thus the more highly developed will be the pore structure. This is especially true for concrete containing slower reacting supplementary cementing materials such as fly ash that require a longer time to hydrate(Tang, 1996),(Bamforth, 1995).

Another influence on the pore structure is the temperature that is experienced at the time of casting. High-temperature curing accelerates the curing process so that at young concrete ages, a high temperature cured concrete will be more mature and thus have a better resistance to chloride ion penetration than a normally-cured, otherwise identical concrete at the same age. However, at later ages when the normally-cured concrete has a chance to hydrate more fully, it will have a lower chloride ion diffusion coefficient than the high-temperature-cured concrete (Detwiler, 1991),(Cao & Detwiler, 1995).This finding has been attributed to the coarse initial structure that is developed in the high-temperature-cured concrete due to its initial rapid rate of hydration as well as the possible development of initial internal microcracking.

The replacement of cement materials in supplementary cementing material fills all voids in the mixture, thus making it homogeneous. In this study, RHA, FA and GGBS improve the resistance of the mixture to salts.

CHAPTER 3: MATERIALS USED AND RESEARCH METHODS

3.1 Introduction

After completion the literatures review. it was determined that the objectives of the study can be achieved with completion the three broad categories investigation of flow characteristics and fresh properties concrete investigation of hardened properties concrete and durable concrete with guideline development to completion all the test according to the specific standard.

The SCC is an engineered material consisting of cement, aggregates, water and admixtures with several new constituents like colloidal silica, pozzolanic materials Portland fly ash (PFA), ground granulated b last furnace slag (GGBS), microsilica, metakaolin, chemical admixtures to take car e of specific requirements, such as, high-flowability, compressive strength, high workability ,enhanced resistances to chemical or mechanical stresses, lower permeability, durability, resistance against segregation, and possibility under dense reinforcement conditions.

3.2 Constituent materials

3.2.1 Natural aggregate

The natural coarse aggregate used in this research was 14 mm nominal maximum size crushed granite. The natural fine aggregate was river sand from Bangi, Malaysia size 4.76 mm and below. A physical analysis of both coarse aggregate and fine aggregate was performed according to ASTM C33-04.02 (2004) specification for concrete aggregates. At chapter 4 can shows the results of the analysis and gradation of the coarse aggregate satisfies ASTM quirements for minimum and maximum percentage passing limits.

3.2.1.1 Coarse aggregate

The specific gravity and absorption was determined according to ASTM C127 (2001).

A representative sample of aggregates was immersed in water for 30 minutes and weighed suspended in water. The sample is then dried 48 hours to saturated surface dry (SSD) condition and weighed.

Finally the sample was oven dried to a constant mass and weighed. The calculations for the specific gravity and absorption are as follows:

$$\text{Bulk dry specific gravity} = A / (B - C) \tag{3.1}$$

$$\text{Bulk SSD specific gravity} = B / (B - C) \tag{3.2}$$

$$\text{Apparent specific gravity} = A / (A - C) \tag{3.3}$$

$$\text{Absorption (\%)} = 100 (B - A) / A \tag{3.4}$$

Where, A = oven-dry mass, B = SSD mass, and C = submerged mass.

3.2.1. 2 Fine aggregate

The specific gravity and absorption was determined according to ASTM C128 (1995). A representative sample of aggregates was immersed in the water for 30 minutes and then dried to SSD condition. The SSD aggregates ware placed in a pycnometer. Water was then added to the constant volume mark on pycnometer and the mass was determined again. Finally, the sample was oven dried to a constant mass and weighed

Figure 3.1 shows all equipment used in the test. The calculation of specific gravity is as follows

Bulk dry specific gravity = A / (B + S - C) 3.5

Bulk SSD specific gravity = S / (B + S - C) 3.6

Apparent specific gravity = A / (B + A - C) 3.7

Absorption (%) = 100 (S - A) / A 3.8

Where,

A = oven-dry mass,

S = SSD mass,

B = mass of the pycnometer filled with water,

C = mass of the pycnometer filled with aggregate and water.

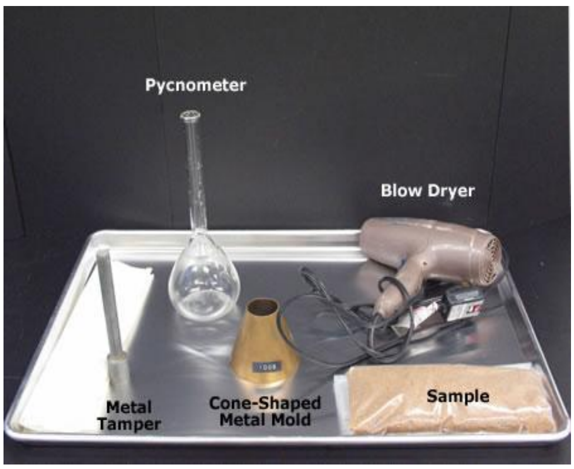

Figure 3.1: The equipment for specific gravity and absorption test for river sand

3.2.1.3 Sieve analysis of aggregate and fineness modulus (FM)

Sieve analyses of coarse and fine aggregates were conducted to determine the size distribution of fine and coarse aggregates. This test method is used to determine the grading of the materials proposed for use in aggregates. It is prescribed in ASTM C136 (1996a). The result is used to complement the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates.

The data may also be useful in developing relationships concerning porosity and packing. While fineness modulus, (FM) is a single parameter to describe the grading curve; it can be useful in checking the uniformity of grading. Small number of fineness modulus indicates fine grading.

In this test, a sample of dry aggregate of known mass is separated through a series of sieves of progressively smaller openings for determination of particle size. Figure 3.2 describes types for coarse aggregate. The sizes of sieves used in the test were: 14 mm, 10mm, 6.3 mm, 5.0 mm, and pan.

Figure 3.2: Type of coarse aggregate used

$$FM(\text{of coarse aggregate}) = \frac{(\textit{Cumulative percent retained on standard} + 400)}{100} \quad 3.9$$

For fine aggregates:

The first group sizes of sieves used in the test were: 2.36 mm, 1.18 mm, , 0.60 mm, 0.300 mm, 0.15 mm, 0.075 mm, and pan.

.

$$\bullet\ FM\ fine = \frac{\text{Cumulative percent retained on standard sieves}}{100} \quad 3.10$$

Where the standard sieves used were 0.15 mm and 0.30 mm, the above Figure 3.3 shows all equipment used in the test. In this study was use the first group size sieves.

Figure 3.3: Sieve analysis equipment for coarse aggregate

3.2.2 Ordinary Portland cement

The raw materials required for the manufacturing of OPC are calcareous material such as limestone or chalk and argillaceous material such as shale or clay. A mixture of these materials is burnt at high temperature of approximately 1400 °C in a rotary kiln to form clinker. The clinker is then cooled and grounded with the requisite amount of gypsum into fine powder known as the Ordinary Portland Cement (OPC) Locally manufactured Ordinary Portland Cement conforming to MS 522: Part 1:2003 Type I was used for all mixtures of the testing program. All cement used was from the same source, (YTL Bhd) and met the requirement of MS 522: Part 1:2003 specification for Portland cement. Its physical properties and chemical compositions are presented in Tables 3.1 and 3.2.

Table3.1: Chemical composition and physical properties of OPC

Element	Concentration (wt%)
MgO	1.29
$Al2O_3$	3.65
SiO_2	16.5
$P2O_5$	0.42
SO_3	4.23
K_2O	0.489
CaO	69.43
TiO_2	0.197
MnO	0.042
Fe_2O_3	3.633
CuO	0.0083
ZnO	0.0094
Rb_2O	0.0049
SrO	0.0399
ZrO_2	0.0141
Total:	99.958

Table 3.2: Standard specifications of ordinary Portland cement used (OPC)

Item	MS 522 part 1 :2003Requirements
Fineness: specific surface (m2/kg)	Min 225
Compressive strength(n/mm2) .Mortar (1:3:0:4) .concrete (1:2:4:0:6)	3 days min 23.0 28 days min 41.0 3 days min 11.5 28 days min 26.0
Setting time :- .initial (minutes) .final (minutes)	 Min 45 Max 600
Soundness/expansion(mm)	Max 10
CHEMICAL Loss on agnation Insoluble residue magnesia (Mgo) sulphates (So_3) lime saturation factor(LSF)	 % max 5.0 % max 5.0 % max 5.0 % max 3.0 0.66<X<1.02

3.2.3 Rice Husk Ash (RHA)

Locally manufactured source of rice husk ash was used and burnt approximately 48 hours under uncontrolled combustion process. The burning temperature was within the range of 600° to 850° C. The ash obtained was ground in a ball mill for 30 minutes and its appearance was in grey color Figure 3.4 below explaining stages preparing this material.

(a) (b) (c)

Figure 3.4: RHA at three stages (a) raw material, (b) after burning, (c) after grinding

3.2.3.1 Chemical composition analysis (XRF) of RHA

XRF compositional analysis results are calculated from background intensity statistics, with background correction and elimination of contaminant if available. Figure 3.5 shows the equipment used were the Bruker S4-Explorer (1kW). Correct sample matrix inputs such as oxide, H_2O, ethanol etc help in getting good results. The physical and chemical characteristics were determined according to the Malaysian standard MS 6: 1998 and chemical properties of RHA shown in Table 3.3 according to this table the chemical characteristics; the RHA has high levels of silicon dioxide, approximately 93%, and the specific gravity 2.16.

Figure 3.5: Bruker S4-Explorer for XRF test (1kW)

Table 3.3: Physical and chemical properties of RHA

Blaine Specific Surface (cm^2/g)		16196
Specific Gravity (g/cm^3)		2.16
Mean Particle size (μm)		12.34
Passing # 325 (%)		96.6
Chemical composition	SiO_2	92.99
	$Fe2O_3$	0.43
	$Al2O_3$	0.18
	CaO	1.03
	MgO	0.35
	SÔ3	0.10
	$Al2O_3 + Fe_2O_3$	0.61
	$SiO_2 + Al_2O_3 + Fe_2O_3$	93.50
	Na_2O	0.02
	K_2O	0.72

3.2.3.2 XRD (X-ray Diffraction) and SEM (Scanning Electron Microscopy)

The X-ray diffraction was used to verify the presence of crystalline silica in RHA and a laser diffraction particle size analyzer was used to determine the particle size distribution of RHA.

Scanning Electron Microscopy (SEM) grams for the RHA sample completed at COMBICAT institute of university Malaya. The SEM showed a very distinct peak corresponding to crystalline silica. The reason for this behavior is the long time combustion process and the high temperatures of burning during prepare the soft material of RHA. As seen in Figure 3.6, the average particle size distribution was 13.34μm. Thus the RHA is finer than cement 32 μm and should be expected to play not only a pozzolanic role, but also have a micro filler effect.

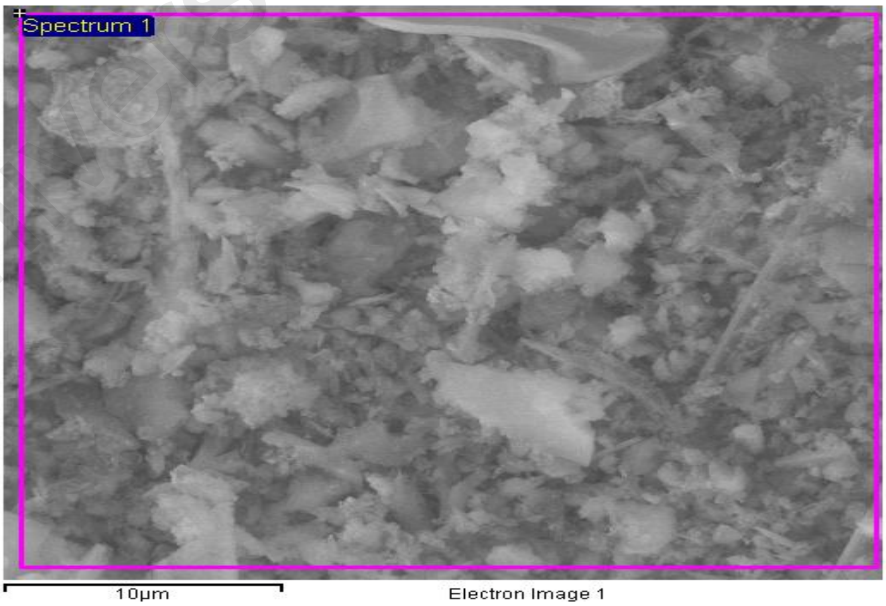

Figure 3.6: SEM image of RHA particle

In this research, RHA was used as a cement replacement. Deleterious materials were burnt 35 to 40 kg each time at temperature within the range of 600° to 850° C out on a furnace the RHA for 72 hours before it was configured for the purpose for the subsequent operations. The sample was then removed and ground using a los Angeles abrasion machine available in the Civil Engineering Materials Laboratory to smaller particle sizes. The sample was tested using an X-ray fluorescence (XRF) spectrometer to determine the chemical composition show the results at the Figure 3.7.

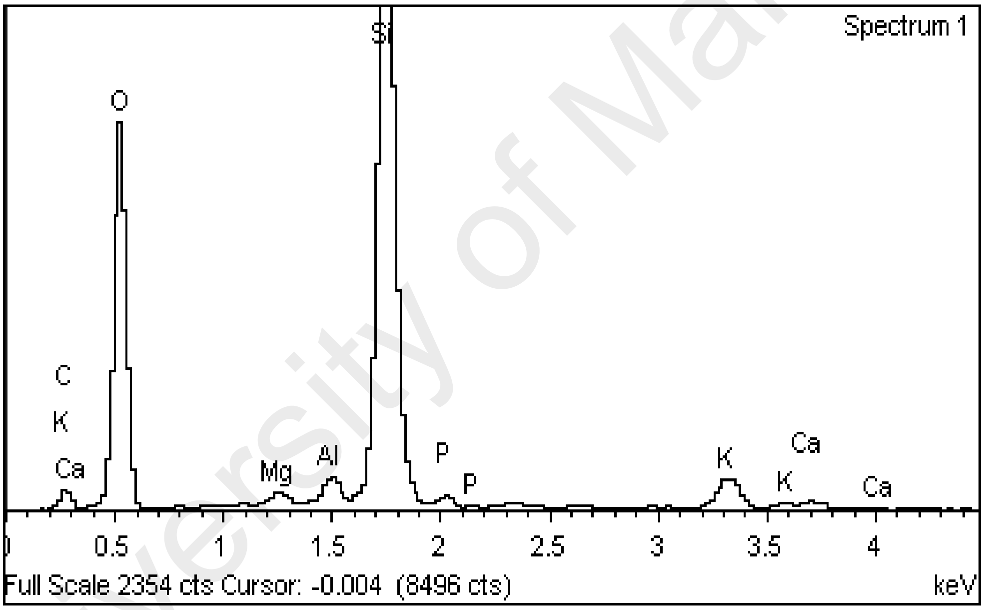

Figure 4.7 Element ratio of RHA XRD

3.2.4 Fly Ash (FA)

The replacement of cement by fly ash in producing concrete is possible up to 50%. However, many concretes that contain Class-C fly ash in the range of 20 % to 40 % of the total cementitious material show equivalent or higher strength than concretes results. containing Portland cement only (Ellis, 1992) .The replacement between ≤ 20% by weight of cement gives better.

In this study FA supplied by YTL Malaysian Cement Company in corporation of fly ash was done according to the requirements of BS EN 450:1995. Mixing with ordinary Portland cement (OPC) by 15% to obtain SCC grade of 40 MPa

3.2.5 Ground Granulated Blast-Furnace Slag (GGBS)

In this study the GGBS supplied by YTL Malaysian Cement Company. The requirements for GGBS according to ASTM C 989-05 (2006) fineness of GGBS is usually greater than 450 m^2/kg and occasionally in excess of 500 m^2/kg.

Detail Chemical analysis was conducted in (Technical Service Compact) University Malaya. The properties of chemical test GGBS are shown in Table 3.6.

3.2.6 Superplasticizer

The requirements for superplasticizers according to ASTM C494-86 Type G and BS 5075: Part 3 was met by Sika ViscoCrete-1600, which facilitates extreme water reduction, excellent flowability with optimal cohesion and strong SCC. Sika ViscoCrete-1600 does not contain chlorides or other ingredients which promote steel corrosion. Therefore, it may be used without restriction for reinforced and prestressed concrete construction, and was used in this study. As explaining in Table 3.7

Table 3.7: Physical and chemical composition of superplasticizer (ASTM, 1986, C494 / C494M)

Attribute	ASTM C494-86. and BS 5075:Part 3
Type	Sika® Viscocrete ®-1600 – G
Color	Dark Brown Liquid
Storage Conditions	Between +5°C and +30°C.
Chemical Base	Aqueous Solution Of Modified Polycarboxylat Copolymers
Density	1.09 ± 0.02
Dosage	Dosage For Concrete SCC 0.5 – 2.0% By Weight Of Cement

3.2.7 Water

The quality of water plays a significant role in the concrete mix. Impurities in water may interfere with the setting of cement and thus may adversely affect the strength of the concrete or cause staining of its surface. The water used for mixing should not contain undesirable organic substances or inorganic constituents in excessive proportions. However, no standards explicitly prescribing the quality of water used for mixing are available. Therefore, water fit for drinking is commonly accepted to be used for concrete mixing.

3.3 Mix-design method

Self-compactability can be largely affected by the characteristics of materials and the mix proportions. A rational mix-design method for SCC using a variety of materials is necessary. Okamura and Ozawa (1995) have proposed a simple mix proportioning system assuming general supply from ready-mixed concrete plants.

The coarse and fine aggregate contents are fixed so that self-compactability can be achieved easily by adjusting the water-powder ratio and superplasticizer dosage only.

3.3.1 Mixing approach

Three methods of mixing can be used: one stage mixing, two stage mixing and three stage mixing. The procedure for each method is as follows:

1. One stage mixing: In this method all the mixing materials are added into the mixer together in one shot. This procedure does not allow the aggregate to have sufficient time to absorb the necessary quantity of water. This causes the concrete mix to have lower compressive strength and workability.
2. Two stages mixing: In this method, the calculated absorption water is added to the aggregate in the first stage and a sufficient time is given to allow the aggregate to be saturated. This solves the problem that arises in the one stage method. In the second stage, the cement and water are added to the mix. However, the aggregate still cannot maintain the water quantity because of its high porosity and the centrifugal forces of the mixer.
3. Three stages mixing: The same procedure of the previous method is applied except that in the second stage, only 20% of water and cement are added in order to provide a covering layer to prevent water addition to cement. The third stage involved addition of 80% of water and cement, to evaluate the effect of the mixing approach on the properties of fresh and hardened self compacting concrete. In this study, the suitable mixing approach method is the Japanese mix proportion(Okamura, 1995) that involves two stages, as the aggregate used does not have high porosity. There is thus no need to use three stages to avoid segregation.

3.3.2 Trial mixes.

Mix design of SCC is very complex because of the wide variability of its material. This information comes from laboratory mixtures or actual mixtures from previous experiments. The result from the aggregate characterization was used to conduct the mix design. Twenty seven trial mixes were conducted and the trial mixes are shown in Table 3.8 the procedure adopted in the study is as follows:-

1) Using the Japanese method of SCC mix design, initial mix design was carried out at coarse aggregate content of 45 % by volume of concrete and fine aggregate content of 55% by volume of mortar in concrete (Okamura, 1995). These trial mixes were designed with superplasticizer content from 1% to 2% for all mixes and strength target of 40 MPa.

2) To proceed towards achieving self compacting concrete using ordinary Portland cement (SCCOPC), the coarse aggregate content was set to 45% by volume of concrete and thereby kept constant. Fine aggregate content was kept constant at 55% by volume of concrete and superplasticizer content at 2% of powder content i.e. cements and mixes SCCOPC1 to SCCOPC3.

3) In the trial mixes TR1 to TR15, we proceed towards achieving the normal SCC with fly ash. The mix TR1 to TR6 powder content has very high. It was reduced fine aggregate content which caused to decrease a slump flow appropriate for specification of SCC. For each trial, the required were not reached in the slump flow test or for the desired target of strength. For mixes TR7 to TR9, by using various percentages of aggregates fine to the coarse (55-45, 60-40, 50-50) led to achieve the good results in the workability, but the results for the strength was not satisfactory.

Mixes TR10 to TR15 were considered as trial mixes, as these mixes fulfill all the requirements of the SCC mix.

But an issue improved specification of SCC was observed that decreased the cement. Mixes SCCFA15, SCCFA10 and SCCFA5 are the SCC mixes that satisfy all the requirements of SCC mixes with fly ash show that in next chapter4.

For SCCRHA (SCC with Rice Husk Ash) mixes, after using different percentages (15%, 10%, 5%) of RHA, the 10% mix was seen to achieve the requirement of SCC with regards to the target strength and workability. Also, after the mixes with GGBS were tested using different percentages (15%, 10%, 5%) of GGBS, the 5% mix proportions for various mixes are given in Table 3.8 and illustrated in Figure 3.8. Further details are given in subsequent sections.

3.5.3 Experimental program.

In this work, four parameters have been investigated, SCC with ordinary Portland cement (OPC), with fly ash (FA), with rice husk ash (RHA), and with GGBS. In the OPC, three mixes with different quantity of cement were used, ie 440,432, and 406 kg/m^3. For FA, RHA and GGBS mixes replacement used (5, 10 and 15%), three different powder ratios were used. Details of these experiments are described in the next section. The experimental work plan is shown in Figure 3.8.

Table 3.8: Trial mix proportions per m^3

Mix. No	W/b %	Cement (Kg)	Fine Agg (Kg)	Coarse Agg (Kg)	Water (Kg)	S.P. (%) binder	Pozzolanic materials (FA,RHA.GGBS)
SCCOPC1	0.5	440	916	750	220	2	0
SCCOPC2	0.52	432	900	679	225	2	0
SCCOPC3	0.53	406	895	732	215	2	0
TR1	0.47	500	752	600	235	1.1	130
TR2	0.49	505	745	570	247	1.1	130
TR3	0.52	510	725	540	265	1.1	130
TR4	0.48	390	780	605	187	1.1	130
TR5	0.54	505	700	550	273	1.1	130
TR6	0.56	510	670	540	286	1.1	130
TR7	0.45	418	920	752	208	2	44
TR8	0.45	418	1002	670	207	2	43
TR9	0.45	418	837	837	208	2	44
TR10	0.5	410	920	752	205	3	50
TR11	0.5	400	931	761	203	3	50
TR12	0.5	418	890	728	229	3	40
TR13	0.52	404	900	679	210	3	50
TR14	0.52	404	945	632	210	3	50
TR15	0.52	385	923	699	200	2	50
SCCFA5	0.53	388	895	732	199	2	18
SCCFA10	0.53	368	895	732	200	2	38
SCCFA15	0.53	349	895	732	201	2	57
SCCRHA5	0.53	388	895	732	201	2	18
SCCRHA10	0.53	368	895	732	201	2	38
SCCRHA15	0.53	349	895	732	201	2	57
SCCGGBS5	0.53	388	895	732	201	2	18
SCCGGBS10	0.53	368	895	732	201	2	38
SCCGGBS15	0.53	349	895	732	201	2	57

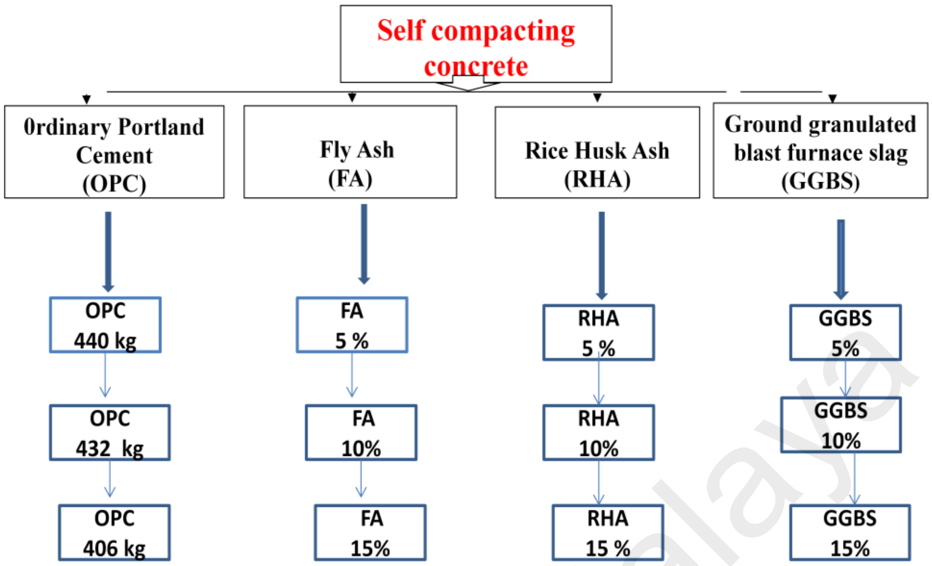

Figure 3.8: Mix proportions for various SCC mixes

3.5.4 Selected mix proportioning

Self-compactability can be largely affected by the characteristics of materials and the mix-proportion. A rational mix-design method for SCC using a deferent ratio of SCM of materials is necessary.

The mix design proposed in this work according to (Okamura, 1995).

• Coarse aggregate content is fixed at 45% of the solid volume;

• Fine aggregate content is fixed at 55% of the mortar volume;

• Water-powder ratio in volume is assumed as 1.2 to 2.0 depending on the properties of the powder and cement.

• Superplasticizer dosage and the final water-powder ratio are determined so as to ensure self-compactability. Slump flow value of 650±30 mm and the V-funnel time of 11±2 sec is taken (ERMCO, 2005). Table 3.9 explains the mix proportion,

Table 3.9: Selected mix proportions of SCC with various admixtures

Mix .no	W/p %	Cement (kg)	F.A (kg)	C.A (kg)	Water (kg)	S.P % of cement	(FA, RHA,GGBS) (kg)
SCCOPC	0.53	406	895	732	215	2	0
SCCFA 15	0.53	349	895	732	201	2	57
SCCRHA 10	0.53	368	895	732	201	2	38
SCCGGBS 5	0.53	388	895	732	201	2	18

3.6 Workability of fresh concrete

No single method has been found to date which characterizes all the relevant workability aspects of SCC. Hence, each mix has been tested by more than one test method for the different workability parameters. In the present work, the workability of SCC is measured using slump flow and the normal slump. The basic equipment used is the same as for the conventional slump test. The test method differs from the conventional one in the way that the concrete sample placed into the mould without used reinforcement rod and when the slump cone removed the sample collaps .V funnel is the other test that takes into account the filling capacity flowability time $T_{50cm,}$ which is a secondary indication of flow-funnel, that indicates the tendency for segregation. The funnel can be refilled with concrete and left for 5 minutes to settle. The L-box test measures the height of the concrete at both ends. The L-box test can give an indication of the filling ability and passing ability.

Finally the slump flow and the normal slump are not enough to determine the flowability of SCC. That means other tests are required to ensure the workability of SCC. According to the EFNARC, 2002 requirement SCC standard Table 3.10 explains the limits of SCC workability.

Table 3.10: Recommended limits for different SCC properties(EFNARC, 2002)

Property	Range
Slump Flow Diameter	500-700 mm
T_{50cm}	2-5 sec
V-funnel	6-12 sec
L-Box H2/H1	≥ 0.8

3.6.1 Slump test

The slump test is prescribed by (ASTM-C143, 2006). The mould for slump test is a frustum of a cone 300 mm high that is placed on a smooth surface with the smaller opening at the top, and filled with concrete in three layers. Each layer is tamped 25 times with a standard 16 mm diameter steel rod, rounded at the end, and the top surface is struck off by means of sawing and rolling motion of the tamping rod according to BS 1881: Part 102 (1983), but to the “displaced original centre” according to ASTM C143-90a (2006). In order to reduce the influence on slump of the variation in the surface friction, the inside of the mould and its base was moistened at the beginning of every test.

Prior to lifting of the mould the area immediately around the base of the cone was cleaned in case there is concrete that has dropped accidentally Figure 3.9 showed that.

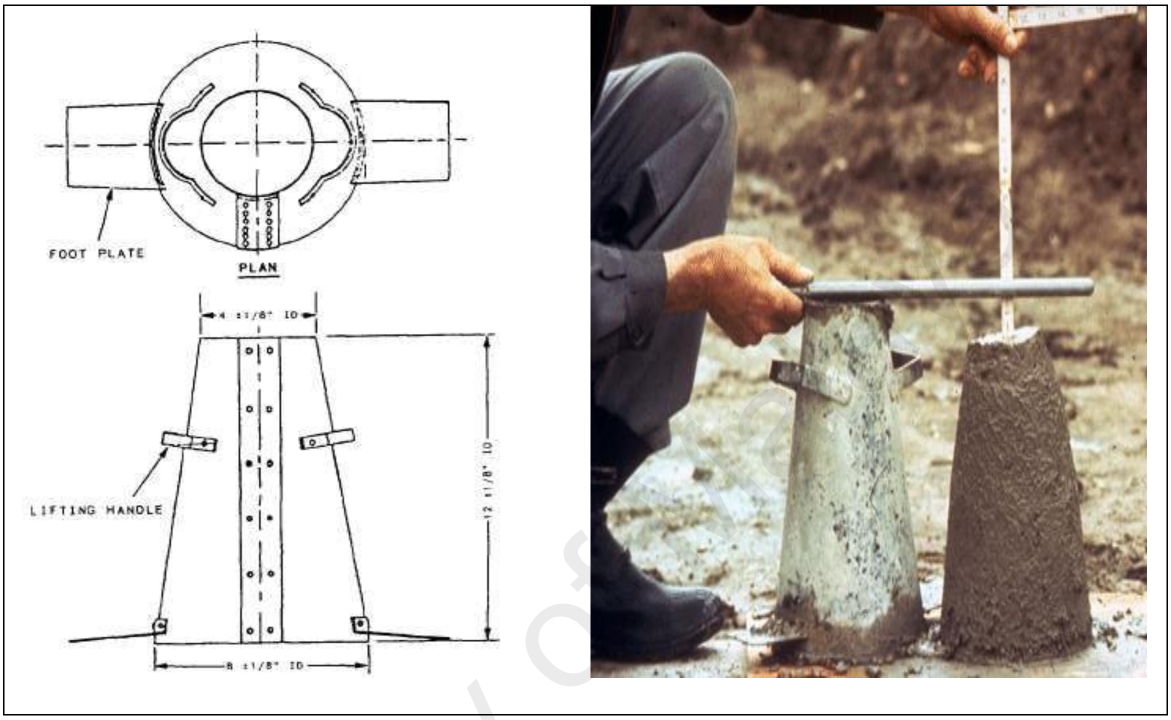

Figure 3.9: Slump test

3.6.2 Slump Flow test

This test is conducted according to EFNARC standard. The required amount of concrete is in this test is at least 6 litters. The slump cone was placed on the level base plate so that it is perpendicular on the table and this table must be fixed on horizontal level. The cone slump must be fixed in the center of the table test. After that we should be cone is filled with concrete then the surface is settled and removed excess concrete from the upper surface of the cone. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reached diameter of 500 mm. Figure 3.10 shows the details requirement

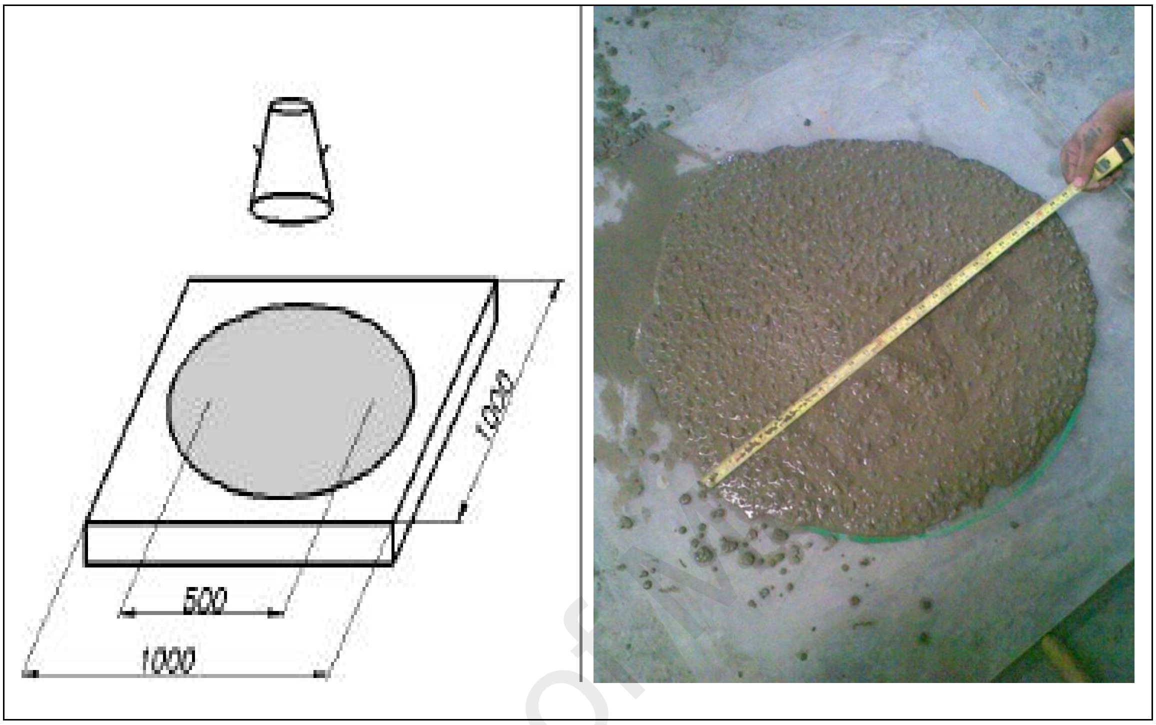

Figure 3.10: Slump flow test

3.6.3 Flowability ($T_{50cm)}$ test

This test conducted according to(EFNARC, 2002) standard. The test method differs from the conventional one in the way that the concrete sample placed into the mould has no reinforcement rod and when the slump cone is removed, the sample collapses. The diameter of the spread of the sample was measured; the horizontal distance was measured instant of the vertical slump measured in the conventional test. While measuring the diameter of the spread, the time that the sample takes to reach a diameter of 500 mm (T_{50mm}) is also sometimes measured. The slump flow test can give indication about the filling ability of SCC and an experienced operator can also detect an extreme susceptibility of the mix to segregation. However, this information cannot be obtained from numerical results alone; a substantial previous experience in using the test and carrying out construction in SCC is essential.

The higher the slump flow (SF) value, the greater is its ability to fill formwork under its own weight. A value of at least 650mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ± 50mm, as with the related flow table test, might be appropriate. The T_{50mm} time is a secondary indication of flow. A lower time indicates greater flowability Figure 3.11 below show the details of T_{50mm} test.

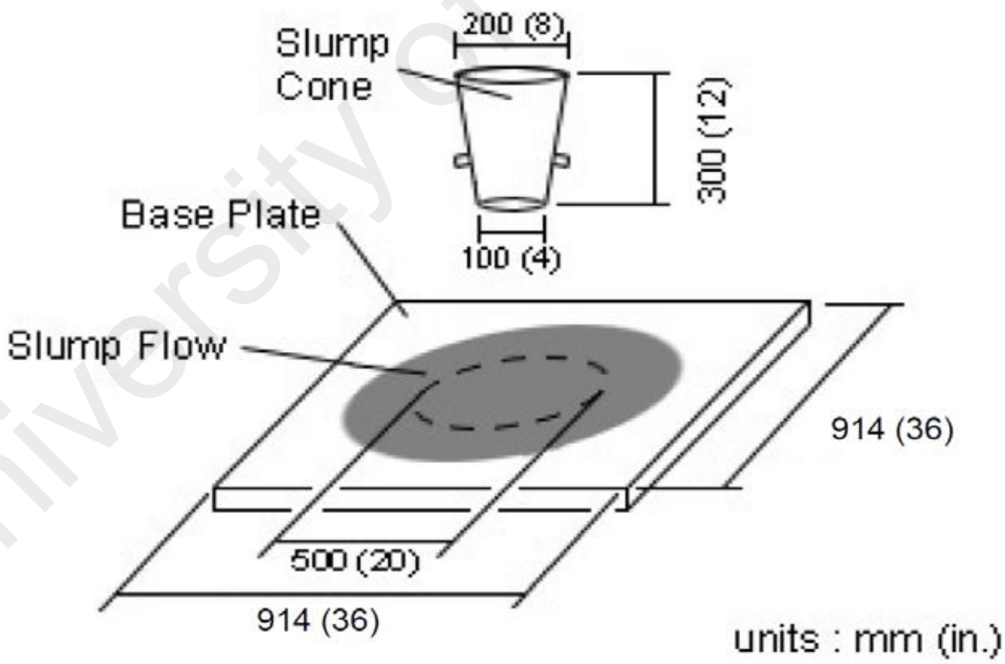

Figure 3.11: Flowability T_{50} test

3.6.4 V- funnel test

The flowability of the fresh concrete can be tested with the V-funnel test, whereby the flow time is measured. According to the (ERMCO, 2005) the instruments used in this test are V-funnel box is shown in Figure 3.12. Clean the funnel and bottom gate, the dampen all the inside surface including the gate Close the gate and pour the sample of concrete into the funnel. Place the container under the funnel in order to retain the concrete to be passed after a delay of (10 ± 2) s from filling the funnel. The funnel is filled with about 12 liters of concrete and the bottom outlet should be closed before testing the time taken for it to flow through the apparatus is measured After a delay of (10 ± 2) s from filling the funnel, open the gate and measure the the V-funnel flow time. Further, T_{5min} was also measured with V-funnel, which indicates the tendency for

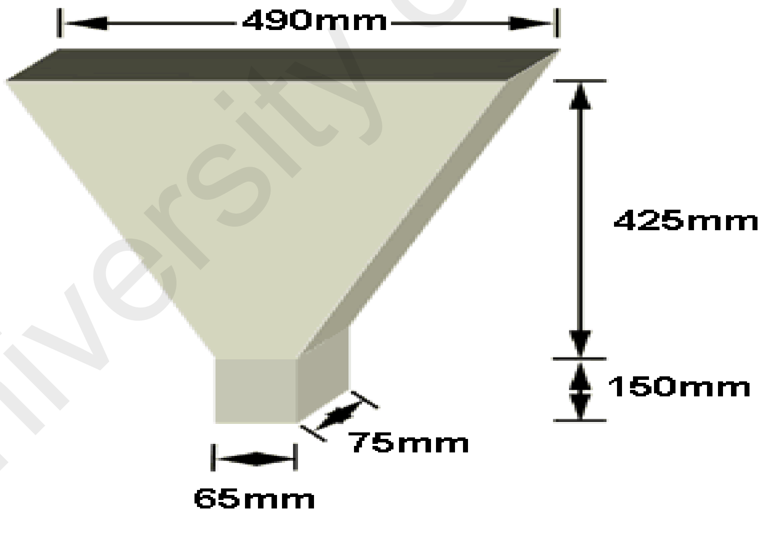

Figure 3.12: V - funnel

Test segregation, wherein the funnel can be refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation, the flow time will increase significantly. According to Khayat and Manai (1996), a funnel test flow time less than 6s is recommended for a concrete to qualify for an SCC.

3.6.5 L-box test

The test is conducted according to (ERMCO, 2005). The test assesses the flow of the concrete, and also the extent to which it is subjected to blocking by reinforcement. The apparatus is shown in Figure 3.13. The apparatus consists of a rectangular-section box in the shape of an 'L', with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are fitted. The vertical section filled with concrete, and then the gate was lifted to let the concrete flow into the horizontal section. When the flow has stopped, the height of the concrete at the end of the horizontal section was expressed as a proportion of that remaining in the vertical section (H2/H1in the diagram). It indicates the slope of the concrete when at rest. This is an indication of passing ability, or the degree to which the passage of concrete through the bars is restricted. The horizontal section of the box can be marked at 200mm and 400mm from the gate and the times taken to reach these points measured. These are known as the T20 and T40 times and are an indication for the filling ability. The sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3 times the maximum aggregate size might be appropriate. The bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete. The passing ability (PA) for the L-box test is calculated from the following equation:

$$PA = H2/H1 \qquad 3.11$$

Where:

H1= concrete height of the end of the vertical section

H2= concrete length in the horizontal section

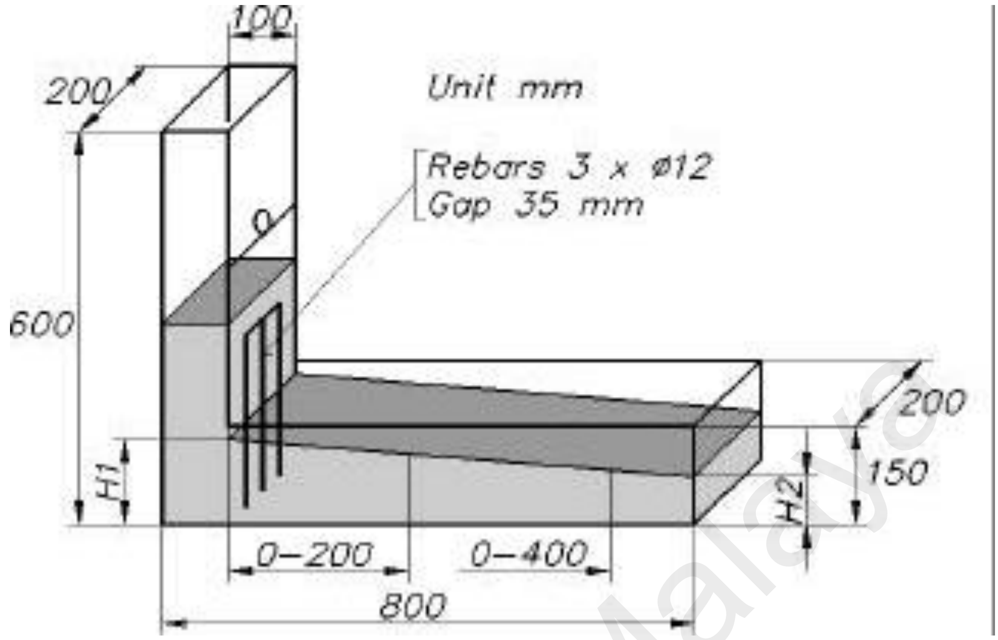

Figure 3.13: The setup of the L-Box test

3.6.6 J-Ring test

The principle of the J-Ring test may be Japanese, but no references are known. The J-Ring test itself has been developed at the University of Paisley. The test is used to determine the passing ability of the concrete. The equipment consists of a rectangular section (30mm x 25mm) open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3 times the maximum aggregate size might be appropriate. The diameter of the ring of vertical bars is 300mm, and the height 100 mm. This involves the slump cone being placed inside a 300 mm diameter steel ring attached to vertical reinforcing bars at appropriate spacing Figure 3.14. Like in the slump flow test, the diameter of the spread and the T-50 time are recorded, but the height of the concrete after the test within the J-ring is also measured.

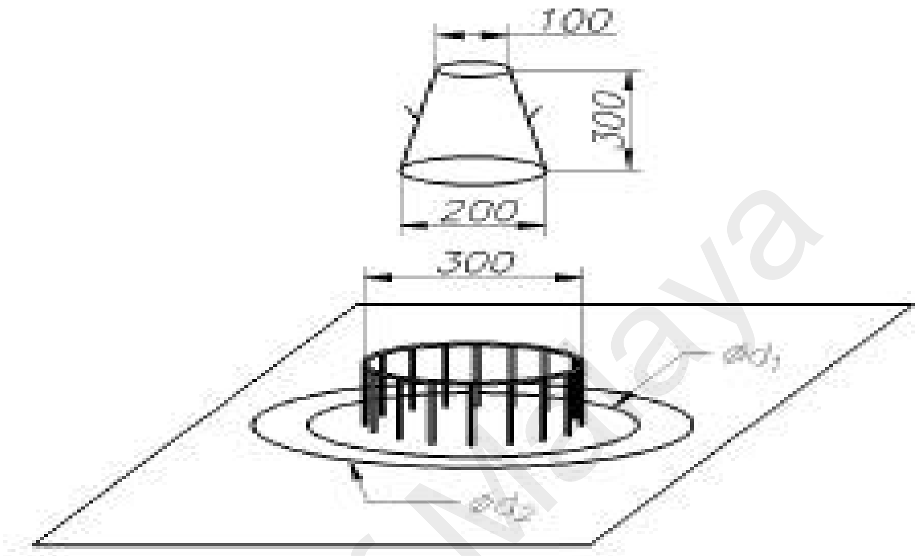

Figure 3.14: The J- Ring used in conjunction with the slump flow

$$PA = H_{in} - H_{out} \quad (3.12)$$

Where:-

PA= passing ability

H_{in} = the high of concrete inside the ring

H_{out} = the high of concrete outside the ring

3.6.7 Segregation test

The segregation test has been developed by the French contractor GTM to assess segregation resistance (stability). It consists of taking a sample of 10 liters of concrete, allowing it to stand for 15 ± 0.5 min to allow any internal segregation to occur, then pouring half of it on to a 5 mm sieve of 350 mm diameter which stands on a sieve pan on a weigh scale. After two minutes, the mortar which has passed through the sieve is weighed and expressed as a percentage of the weight of the original sample on the sieve. The limit for the concrete segregation test 20% (ERMCO, 2005).

$$SR = \frac{Wps - W\,p}{Wc} \times 100 \qquad 3.13$$

When:

SR = Segregation Resistance

Wps = Mass of the Receiver and Concert

W p= sieve receiver

Wc= actual mass of concrete

Figure 3.15 Segregation test method

3.7 Testing and curing of test specimens

Some tests are conducted to determine the effects of SCC on workability, durability and compressive strength of concrete as well as to determine the optimum mix proportions. Details are provided in the following section.

The British Standard(BS, 1881-111: 1983) describes the method of normal curing of concrete specimens (cubes, beams or cylinders made in accordance with Parts 108, 109 and 110 of this British Standard) at 20 °C for strength tests at ages of 1 day and over.

3.8 Properties of hardened concrete.

3.8.1 Compressive strength test

The compressive strength of the concrete specimens was determined according to BS EN 12390-4 (2000). Three cubes specimens have been used. The specimens are cast in steel or cast-iron moulds of robust construction, generally (100 x 100 x 100) mm, testing for concrete samples was conducted at 7,28,90,180,360 and 660 days. For this study, three specimens were used for test at each age. The machine which was used the automatic type with 2000 KN capacity as shown in Figure 3.15.

Compressive strength (fc) was obtained by dividing the maximum load (N) by the area of the sample applied to load (mm) and taking the averaging of three cups for each age.

Compression strength $fc = P/A$ 3.14

Where:-

P = applied load on the sample, N,

A = the exposed area of the sample to load mm^2

Figure 3.16: Equipment for compressive strength test

3.8.2 Flexural strength test

The flexural strength of the concrete specimens was determined according to(BS, 1881: Part 118,1983e) method for determination of flexural strength used of the beam size was (100 x 100 x 500) mm. The beam specimens were tested at the ages of 28 and 180 days.

The beam specimens were loaded to failure at a rate of 0.02 MPa/s. Figure 3.17 Six beam specimens for each mixture were tested. Three of the specimens were tested at 28 days to permit an early evaluation of the mix. The remaining beams were tested at 180 days. The modulus of rupture was calculated by the equation following:

$$f_r = PL / BD^2 \qquad 3.15$$

Where:

f_r = modulus of rupture (N/mm^2)

P = maximum applied load (N)

L =span length (mm)

B = width of the specimen, (mm)

D = depth of the specimen, (mm)

Figure 3.17: Equipment for flexural strength test

3.8.3 Splitting tensile strength

The determination of splitting tensile strength was done according to (ASTM, C496, 2006). The specimens of splitting tensile strength were cylinders. Tests were performed on (150ϕ x 300) mm specimens at the ages of 28 and 180 days, which were loaded to failure at a rate of 0.02 MPa/s. The splitting tensile strength was determined using Equation 3.16. (P) is the maximum load at failure in KN, and (l) and (D) are the length and diameter of the cylindrical specimen, respectively, in mm.

$$f_t = \frac{2P}{\pi l d} \qquad 3.16$$

Where:

P = is the applied compressive load, (N)

l = is the cylinder length, (mm)

D = the cylinder dimeter, (mm)

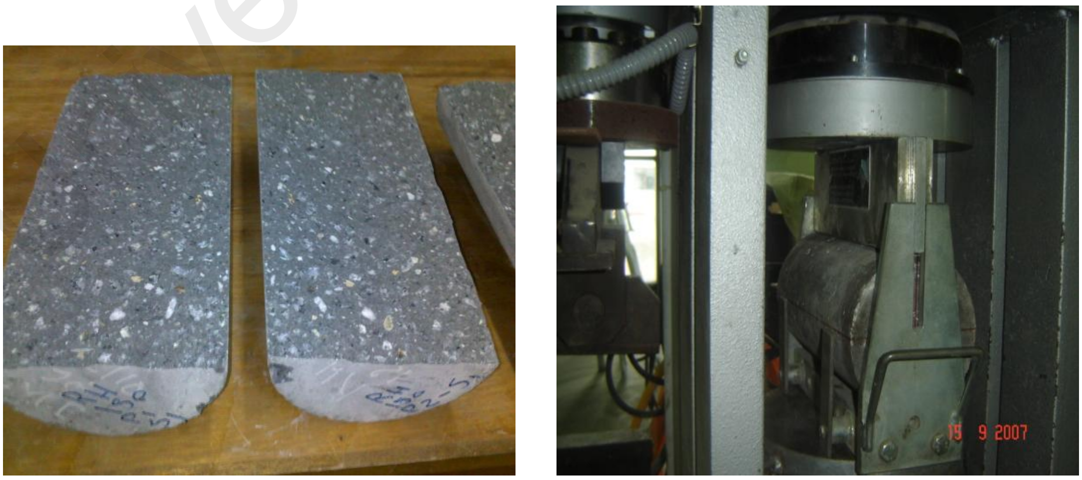

Figure 3.18: Sample for splitting tensile test

3.8.4 Static Modulus of Elasticity

The test was conducted in accordance with (ASTM, C469,1987). In this test, six cylinders from each mix were tested. Three samples were tested at 28 days and the remaining cylinders were tested at 180 days. An elastic modulus, or modulus of elasticity, is the mathematical description of an object or substance's tendency to be deformed elastically when a force is applied to it. The elastic modulus of concrete an object is defined as the slope of its stress-strain curve in the elastic deformation the rate with normal SCC 28 GPa according to (ASTM, C469,1987) .

In this thesis, the modulus of elasticity was examined and software was used to calculate the deformation in the longitudinal and transverse direction. The compressive machine was calibrated to apply one third of the maximum load with the purpose of obtaining a strength grade of 40 MPa. After application of the load, all the results were saved onto a notebook connected to a data logger.

Modulus of elasticity can be computed as:-

$$E_c = \delta\sigma / \delta\varepsilon = \frac{\sigma_a - \sigma_b}{\varepsilon_a - \varepsilon_b} \qquad 3.17$$

Where:

σ_a = the upper loading Stress = f_{cyl} /3 (N/mm^2)

σ_b = the basic stress (0.5 N/mm^2);

$\delta\sigma$ = the main Strain under the upper loading stress;

$\delta\varepsilon$ = the main Strain under the basic stress

3.8.5 Poisson's Ratio test

When a sample of material is stretched in one direction it tends to get thinner in the other two directions longitudinal and transverse direction. Poisson's ratio is the ratio of the relative contraction strain, or transverse strain normal to the applied load, to the relative extension strain, or axial strain in the direction of the applied load. the Poisson's ratio of the concrete is in the range 0.2.

Poisson's Ratio can be expressed as:

$$\upsilon = -\varepsilon_t / \varepsilon_l \quad 3.18$$

Where:

υ = is the Poisson's ratio,

ε_t = is the transverse strain and,

ε_l is the longitudinal or axial strain.

Strain can be expressed as

$$\varepsilon = \Delta_L / L_O \quad 3.19$$

Where:

Δ_L = is the change in length and

L_O = is the initial length.

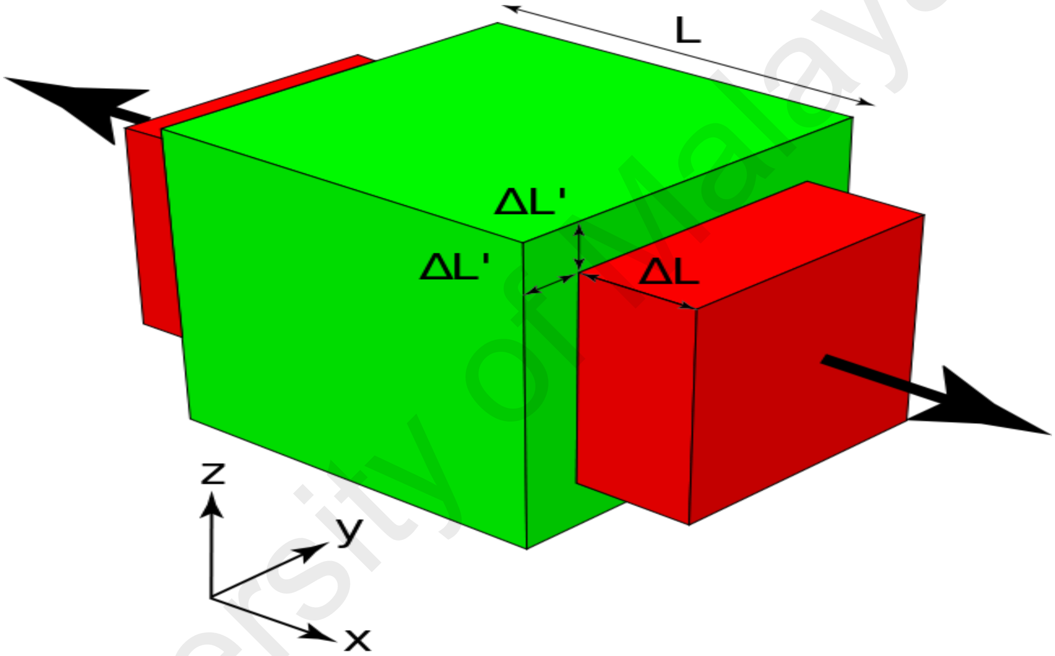

Figure 3.19: The deformation in the longitudinal and transverse directions

3.8.6 Ultrasonic Pulse Velocity (UPV)

Each prism was prepared for the ultrasonic pulse velocity (UPV) test as described was tested according to (BS, 1881-203:1986). The (100x100x500) mm beams were tested at the ages of 28 and 180 days. . The pulse velocity should be measured between moulded faces for cubes. For each specimen, there should be at least three measurements spaced between its top and bottom and the mean value recorded. The ultrasonic pulse is created by applying a rapid change of potential from a transmitter-driver to a piezoelectric transformation element that causes it to vibrate at its fundamental frequency. The transducer is placed in contact with the material so that the vibrations are transferred to the material. The vibrations travel through the material and are picked up by the receiver. The wave velocity is calculated using the time taken by the pulse to travel the measured distance between the transmitter and the receiver.

The display indicates the time of travel of the ultrasonic wave. The equipment for the UPV test is as shown in Figure 3.20.

The pulse velocity can be determined from the following equation

$$V = L/T \qquad 3.20$$

Where

V=Ultrasonic pulse velocity (m/s)

L= path length (mm), and,

T= effective time (μ sec)

Figure 3.20: Equipment for UPV test

Table 3.11: The quality of concrete in structures in terms of UPV (BS, 1881-203:1986)

Ultrasonic pulse velocity (m/ s)	Concrete quality (Grading)
Above 4.5	Excellent
3.5 t0 4.5	Good
3.0 to 3l.5	Medium
Below 3.0	Doubtful

3.8.7 Shrinkage and expansion

Shrinkage is a time dependent phenomenon, which is measured by an instrument with a gauge of 0.002 mm accuracy. The test was conducted in accordance with (ASTM, 878/ C878M-03, 2006). It uses cylinders of 150 mm diameter 300 mm length at tested ages of 7, 28, 90, 180 and 360 days under two types of curing regimes, namely, wet air drying and wet curing. Demec discs were placed on all specimens soon after demoulding in the middle of three longitudinal directions. Samples were cured for 7 days then shrinkage tests were conducted. One of the reasons for the use of SCC is to improve the properties of concrete structures. However, the drying shrinkage of SCC may be large because SCC contains a large amount of cement and filler. Therefore, resistance to shrinkage cracking in SCC is investigated in this research. Values of drying shrinkage and wetting expansion of concrete are often useful to measure at the time of mix design trials to ensure the concrete will exhibit values that are within normal ranges for concrete. The test consists of making a number of cylinders of the concrete of known exact length, then either subjecting them to a drying or wetting Environment.

Any change is length over time is then recorded. The Figure 3.21 showed the equipment Used.

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Figure 3.21: Dial gauge equipment for shrinkage test

Through loaded at stress-strength ratios of 0.3 of the cubic compressive strength Readings were obtained at ages 28, 90,180 and 360 days. Creep strain was calculated by subtracting the shrinkage strain and elastic strain from the total of the creep specimen measured at zero stress the Figure 3.21 shows the specimenns.

From the test, we can calculate creep strain by subtracting shrinkage strain and elastic strain from the total strain of creep specimen measured at zero stress as shown in equation (3.20).

$$\varepsilon_c = \varepsilon_t - \varepsilon_{sh} \qquad 3.21$$

Where is strain:-

ε_t = is total strain,

ε_{sh} = is free shrinkage strain.

3.9 Durability of hardened concrete

3.9.1 Initial surface absorption

The initial surface absorption test can be used as a measure of the durability near the surface cover of the concrete. In this test, six cubes size (100 x 100 x 100) mm were used and tested at 28 days and 180 days. The test was conducted to determine the initial surface absorption rate of the concrete, which is the rate of flow of water into the concrete matrix per unit area after being subjected to a constant water pressure for a specified period of time. The test method is prescribed in (BS, 1881: Part 208: 1996).

Table 3.12 determine the period during Take the reading normally after the following intervals from the start of the test 10, 30, and 60 min. at each of the specified test intervals close the tube to allow water to flow back along the capillary tube. When the meniscus reaches the scale start which movement is to be measured. Figure 3.22 shows the diagram of ISAT equipment test

Table 3.12: Determination of period of movement (BS, 1881: Part 208: 1996)

Number of scale division moved in 5s	Period during which movement is measured
< 3	2 min
10 to 9	1 min
10 to 30	30 s
>30	Record initial surface absorption as more than 3.60 ml/(m^{2}·s)
NOTE 1 division= 0.01 unit	

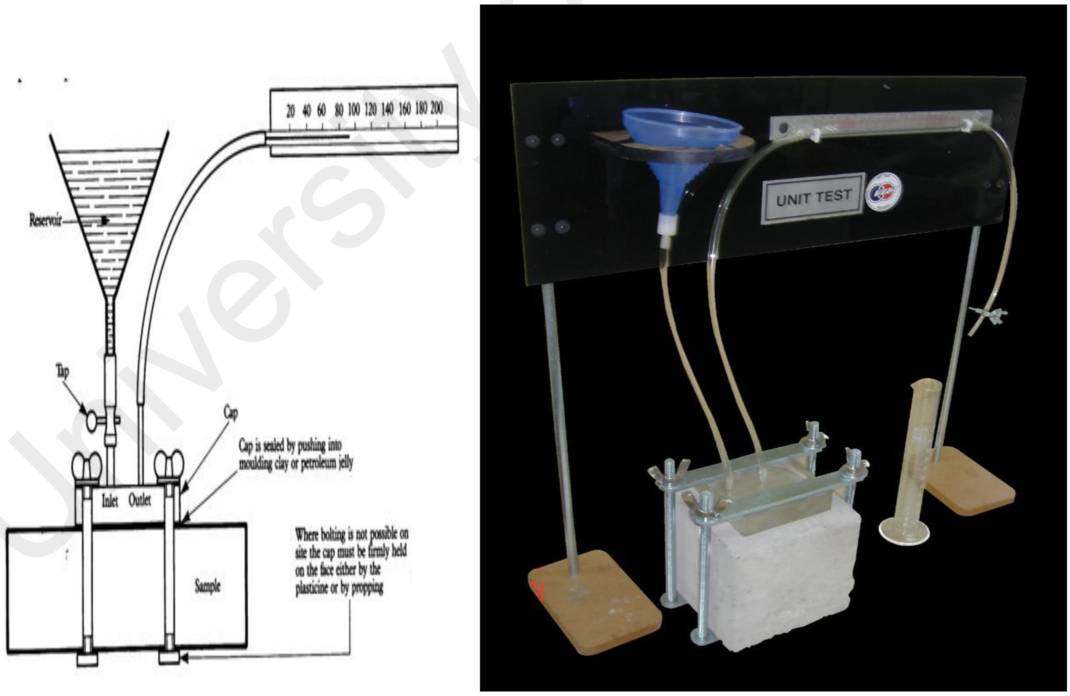

Figure 3.22: Equipment for I-SAT

3.9.2 Absorption test

Absorption tests are simple to perform and can be done by any materials lab. The test measures the weight of water absorbed into a concrete specimen over time according to (BS, 1881 Part 122. 1983), six separate specimens, sizes (150x150x150) mm were used to determine the absorption of SCC concrete. The specimens were put into an oven to dry at 105° C for 72 hours. The specimens were then weighed and the weight recorded. Immediately, the specimens were immersed in a water tank for 30 minutes. The distance from water surface to the top surface of immersed concrete cube must be more than 25 mm. After 30 minutes, the specimen was taken out. Cloth was used to remove the water on the concrete surface quickly without absorbing the water within concrete cube. The specimen was weighed again.

The difference in mass of the specimens is the mass of the water absorbed Water absorption can be shown through the mass, or more accurately by dividing it with the total surface area giving the mass per unit area. Figure 3.23 show the sample used for determine the water absorption under absorption conditions water absorption can be calculations by the following equation:

$$A = [(Ms - Md) / Md] \times 100\% \qquad 3.22$$

A= absorption value %

Ms= weight of surface dry sample in air (kg)

Md = weight of oven-dry sample (kg)

Figure 3.23 Specimen used for water absorption

3.9.3 Porosity test

Three saturation techniques were used to determine the permeable porosity of concrete(ASTM, C 642,2002). ASTM standard procedures were employed in cold-water and boiling-water saturation techniques using 100 mm by 50 mm cylinder specimens Figure 3.24 explain that. The specimens were dried in the oven at 105 °C for more than 48 h to determine the oven-dry mass. In order to determine the saturated surface-dry mass in cold-water saturation technique, the specimens were simply immersed in cool water at approximately 21° C for more than 48 h. During boiling-water saturation, the specimens were boiled in a receptacle for 5 h and then allowed to cool for 19 h to a final temperature of 20–25° C. In vacuum saturation, the oven-drying process was the same as that in cold-water and boiling-water saturation techniques. The specimens were removed from the oven, cooled in dry air to a room temperature of 20–25°, C and then weighed to obtain the oven-dry mass.

Finally, for all saturation techniques, the permeable porosity of concrete was calculated based on the concept of weight gain due to water absorption and weight loss because of buoyancy. The following Equation (3.22) was used to calculate the permeable voids of concrete:

$$\text{Permeable voids} = \frac{W_s - W_d}{W_s - W_b} * 100\% \qquad 3.23$$

Where:-

W_b = Buoyant mass of the saturated specimen in water, (g)

W_d = Oven-dry mass of the specimen in air, (g)

Ws = Saturated surface-dry mass of the specimen in air, (g)

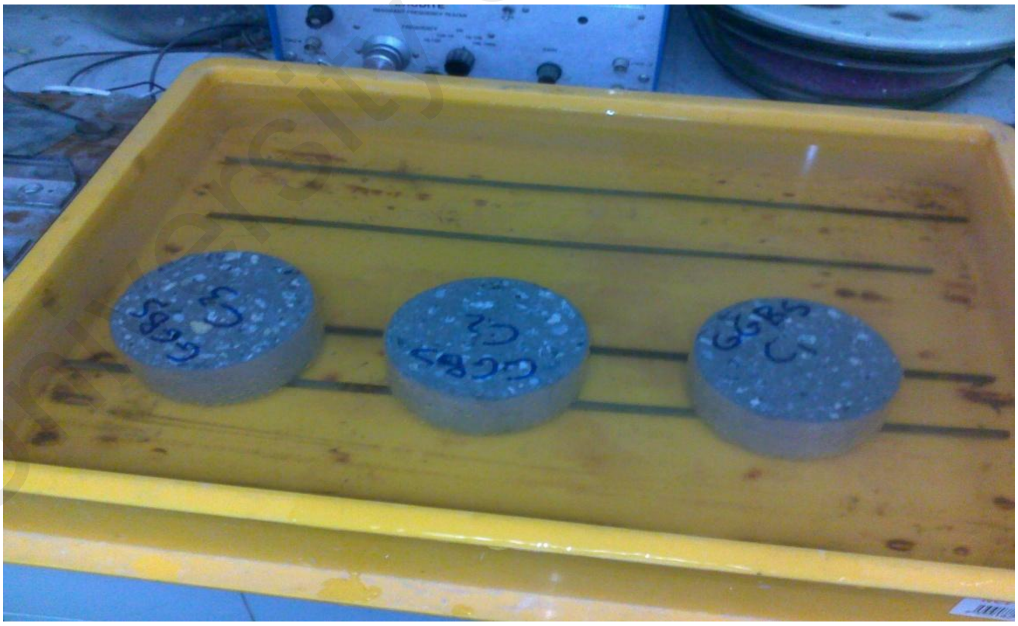

Figure 3.24: Samples for porosity test

3.9.4 Resistance to magnesium sulphate attack

The salt used in the study was magnesium sulphate hydrate dissolved in water with the content of 5%. according to (ASTM, C1202,2006). All the specimens were initially cured in water for 7 d after demolding. Then, they were immersed in the magnesium sulphate solution. The sulphate immersion was conducted for three cycles; each cycle consisting of 30 d of sulphate immersion followed by 7 d of air drying; tests were conducted at the end of each cycle. The sulphate solution was replaced every 15 d during each cycle.

The length and mass changes were monitored on three concrete cube specimens of (100 x 100 x 100) mm. For length change measurements, four readings were taken from each specimen at the end of each immersion cycle. The average length was then recorded and the results were expressed as a percentage with respect to the length changes, with the other samples left in the curing tank at the same age and during the drying age.

After 24 h from casting, the cubes were demolded and moved to the water tank or the 7th day; the specimens were divided into three groups. The first groups was immersed in the sulphate solution, the second was kept in water while the third was left in the lab conditions. The test was done at the end of each immersion cycle at 44, 81, and 118 d; compressive strength was determined as the average value taken from the three specimens (Habeeb & Mahmud, 2010). Observing the optical appearance of the test samples, as shown in Figure 3.25

a) SCCFA   b) SCCRHA

c) SCCOPC   d) SCCGGBS

Figure 3.25: Visual observation of the concretes exposed to MS, water and the drying age of SCC contain various SCM at 118 days

3.9.5 Chloride penetration resistance test (RCPT).

In 1981, a more convenient test known as the Rapid Chloride Permeability Test (RCPT) was developed by the Federal Highway Administration. This test was adopted by (AASHTO, T277,2007) standard method of test for electrical indication of concrete's ability to resist chloride ion penetration and adopted as(ASTM, C1202,2006) the test method covers the determination of the electrical conductance of concrete by subjecting

A saturated concrete specimen with a diameter of (100 mm) and a thickness (50 mm) to 60 volts DC for six hours One side of the specimen is immersed in a sodium chloride solution and the other side in a sodium hydroxide solution.

The side of the cylindrical specimen is coated with epoxy, and after the epoxy is dried, it is put in a vacuum chamber for 3 hours. The specimen is vacuum saturated for 1 hour and allowed to soak for 18 hours. It is then placed in the test device. The left-hand side (–) of the test cell is filled with a 5% NaCl solution.

The right-hand side (+) of the test cell is filled with 0.3N NaOH solution. The system is then connected and a 60-volt potential is applied for 6 hours. Readings are taken every 30 minutes. At the end of 6 hours the sample is removed from the cell and the amount

of coulombs passed through the specimen is calculated. The test results are compared to the values in the Table 3.14 below. This table was originally referenced in AASHTO T277-83 and ASTM C1202 specifications. The Figures 3.26 and 3.27 shows the details of equipment used .

Table 3.13: Chloride permeability based on charge passed (ASTM, C1202,2006)

Charge Passed (Chloride)	Chloride permeability	Typical concrete type
>4,000	High	High W/C ratio (>0.60) conventional PCC
2,000–4,000	Moderate	Moderate W/C ratio (0.40–0.50) conventional PCC
1,000–2,000	Low	Low W/C ratio (<0.40) conventional PCC
100–1,000	Very Low	Latex-modified concrete or internally-sealed concrete
<100	Negligible	Polymer-impregnated concrete, Polymer concrete

Figure 3.26: Equipment for RCPT

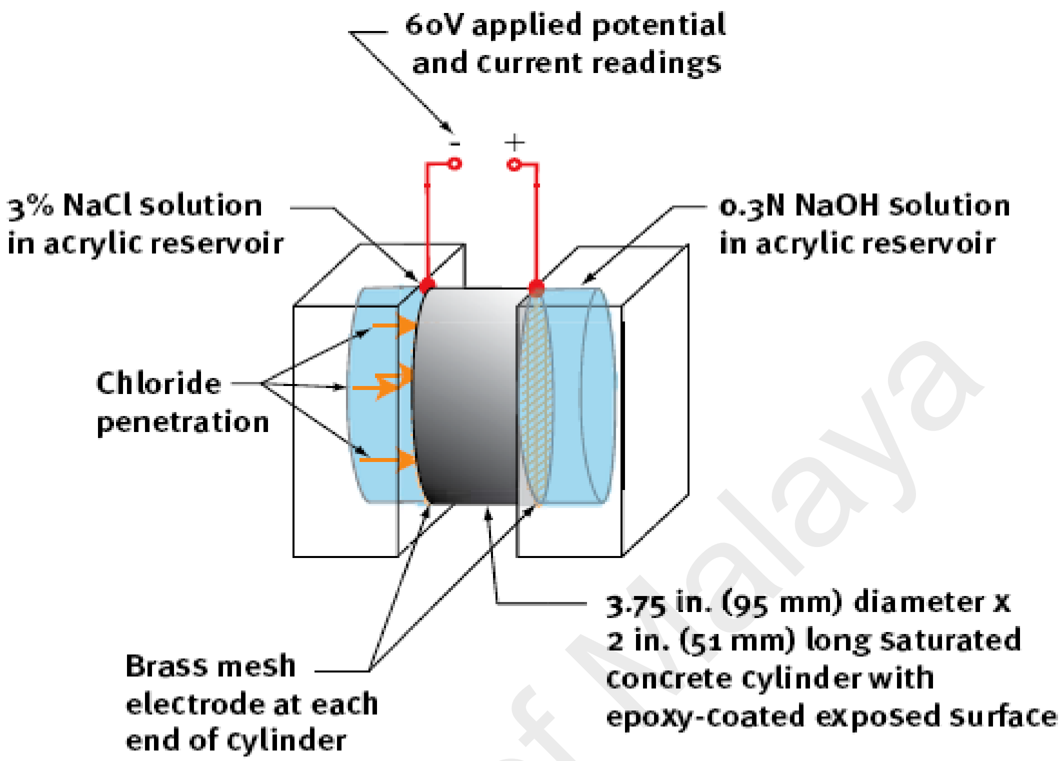

Figure 3.27: Details of cell of RCPT equipment test

CHAPTER 4: CONCRETE INGREDINETS AND MECHANICALPROPERTIES OF SCC

4.1 Introduction

Supplementary cementitious materials SCM and aggregates consisting of stones or stone-like solids are coarse, inert, inorganic materials which are widely used and the main composition (three quarter volume) in the production of Portland cement concrete. Therefore, aggregates provide significant effect on the characteristics of both freshly mixed and hardened products. This chapter presents the experimental results obtained in this research. Analyses and evaluation of the results are also presented.

4.2 Characterization of Aggregate

This kind of aggregate was taken from natural deposits without changing their nature during the process of production such as crushing and grinding. Results of sieve analysis, specific gravity, and absorption of the coarse and fine aggregate are presented in details as follows:

4.2.1 Sieve analysis

The sieve analysis results of crushed gravel and sand are shown in Figures 4.1 and 4.2 respectively.

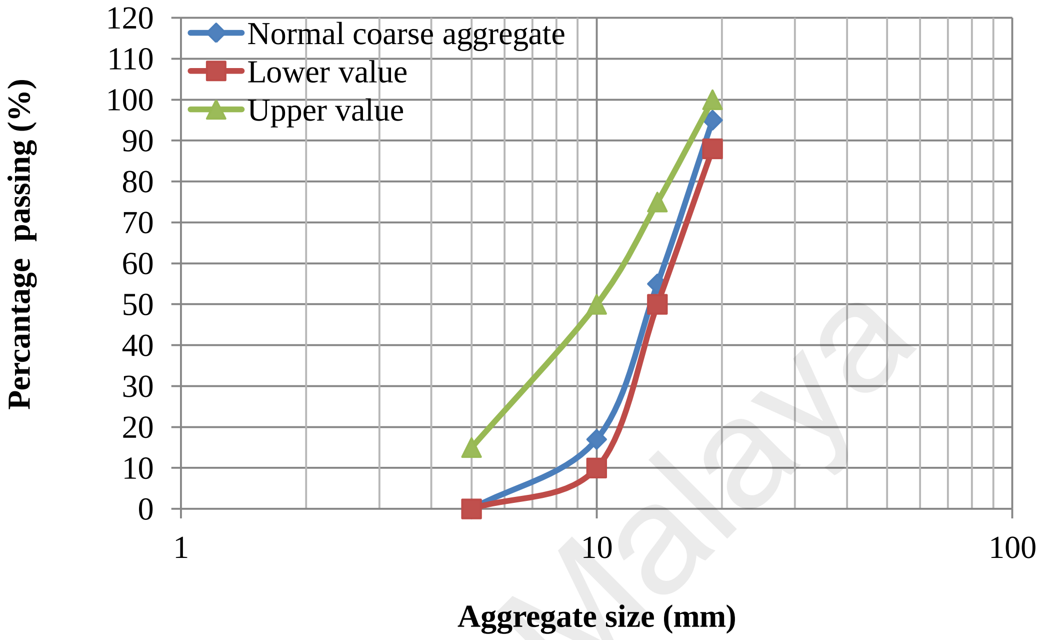

Figure 4.1: Sieve analyses for the normal coarse aggregate

The percent passing for the coarse gravel with 19 mm maximum size is within the range specified for normal coarse aggregate (ASTM, C136. 1996a) (Figure 4.1). This implies that the coarse aggregate can be convenient for concrete making. With aggregate gradation, the gap left (void) is lessened and minimum ingredients of water, cement, and fine aggregate would be sufficient to fill the voids to obtain a compact mass of concrete. This ensures an economical design of the mix proportions.

The percent passing for the fine aggregate is also fairly within the range specified by (ASTM, C136. 1996a). However, the percent passing for sieve size in the range 1.18 mm to 2.34 mm is slightly higher. This is still in order as this range of particles gradation is very small. It only means that a lower amount of cement is probably required to maintain yield. The particle gradation is favorable for minimum cement paste content to fill the void of the fine aggregate adequately.

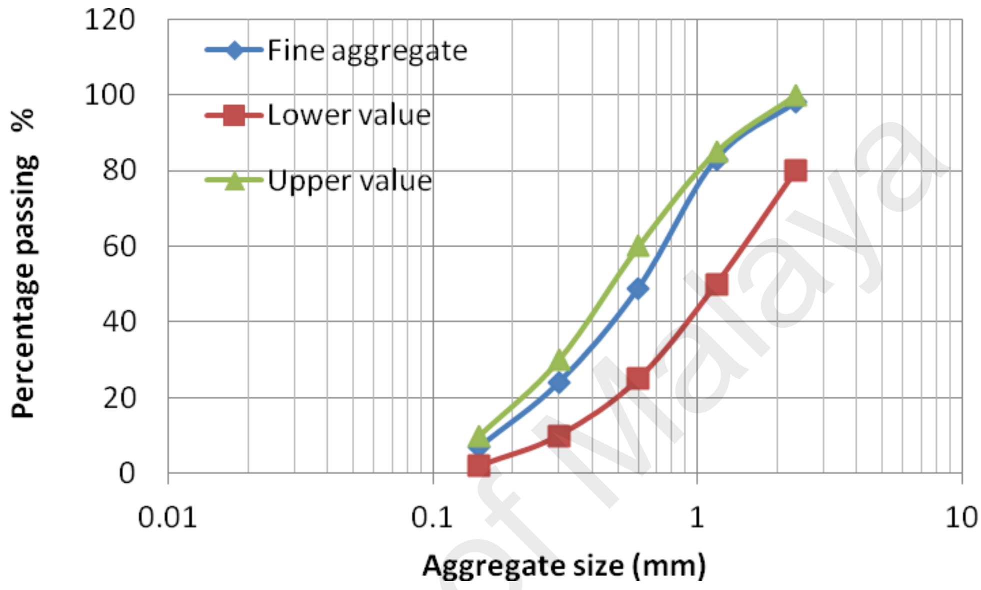

Figure 4.2: Sieve analyses for the normal fine aggregate

4.2.2 Specific gravity and absorption

Results of specific gravity and absorption for the coarse and fine aggregate are presented in Tables 4.1 and 4.2, respectively. Test results show that the absorption capability of both fine and coarse aggregate are at the standard range, 2.73% and 1.43% respectively. The specific gravity and absorption was determined according to (ASTM, C127, 2001) and (ASTM, C128-1995) respectively.

Table 4.1: Specific gravity and absorption of coarse aggregate

Test –No	Specific gravity			Absorption (%)
	Oven-dry	SSD	Apparent	
1	2.40	2.59	2.99	1.3
2	2.41	2.62	3.06	1.8
3	2.39	2.61	3.07	1.2
Average	2.40	2.61	3.04	1.43

Table 4.2: Specific gravity and absorption of sand

Test .No	Specific gravity			Absorption (%)
	Oven-dry	SSD	Apparent	
1	2.23	2.33	2.46	2.2
2	2.30	2.4	2.5	3.1
3	2.40	2.5	2.6	2.9
Average	2.31	2.39	2.50	2.73

4.3 Ordinary Portland cement (OPC)

Locally manufactured Ordinary Portland Cement (OPC) conforming to (MS, 522: Part 1:2003) was used for all mixtures of the testing program. All cement used was from the same source; the chemical properties and composition of OPC used in this study and the MS 522: Part 1:2003 are presented in Table 3.1.

Table 4.3: Chemical composition of cement

Oxide	Concentration (wt %) MS 522: Part 1:2003	Actual concentration (wt %)
MgO	3.0	1.70
Al_2O_3	3.65	4.19
SiO_2	15.5	21.23
SO_3	3.0	2.20
K_2O	0.429	0.61
CaO	67.43	65.2
Fe_2O_3	2.61	3.34
LOI	5.0	1.50
Total:	99.969	99.97

4.4 Rice Husk Ash (RHA)

Rice husk was burnt approximately 24 hours under uncontrolled combustion process. The burning temperature was within the range of 600° to 850° C. The ash obtained was grounded in a ball mill for 5000 cycle by Los Angeles machine to get the fineness of 45μm and its appearance color was grey. It contained 87% of silica.

The results are summarized and shown in Table 4.4. The actual silica contents used is very high; therefore, we were able to get a good resistance commensurate with the ratio of silica.

Detailed chemical analysis was conducted in Combinatorial Technology and Catalysis Research Centre (COMBIACT), University of Malaya and the results are summarized in.

Table 4.4 Weight percent of RHA sample in elemental and oxide form

Weight percent of RHA sample in elemental form		Weight percent of RHA sample in oxide form	
Element	Concentration	Element	Concentration
SiO_2	87.70	O	50.84
P_2O_5	2.66	Si	41.40
SO_3	0.80	P	1.21
K_2O	4.32	S	0.32
CaO	1.20	K	4.58
MnO	0.08	Ca	0.88
Fe_2O_3	0.84	Mn	0.07
ZnO	0.03	Fe	0.64
LOI	2.30	Zn	0.02
Total	99.93		99.95

4.5 Fly Ash (FA)

In this study, the replacement of fly ash was able to meet the requirement of (BS, 1995, EN 450) with OPC at 15% for concrete. According to the requirements of self-compacting concrete, it is in accordance with concrete strength target of 40 MPa. The properties are shown in Table 4.5

Table 4.5: Chemical composition and engineering properties of fly ash

Attribute	BS EN 450:1995	Actual properties
45 µm sieve Residue	(%) Max 40.0 better write <40.0 %	38.0 %
Loss on ignition (LOI)	(%)Max 6.0	3.2%
Sulphuric Anhydride(SO_3)	(%)Max 3.0	1.9%
Silica (SiO_3)	(%)Min 25.0	41%
Chloride (CI)	(%) Max 0.10	0.5%
Free calcium oxide (CaO)	(%)Max 1.0	0.7%
Activity Index :28 Day :90 Days	(%) Min 75 (%) Min 85	(%) Min 75 (%) Min 85
Soundness	(mm) Max 10	(mm) Max 10

4.6 Ground Granulated Blast Furnace Slag (GGBS)

Detailed chemical analysis was conducted in the COMBIACT, and the results are summarized in Table 4.6.The chemical tests show the elements in the material and only serve as a pretest for chemical analysis.

Fineness of GGBS is usually greater than 350 m^2/ kg and is occasionally in excess of 500 m^2/ kg. Specific gravity is 2.9 (Neville, 1995). In this study, the properties of GGBS showing in Table 4.6 conforming to the specification the percentage of silica SiO_2 ratio in GGBS is less than other SCM also the Loss on Ignition (LOI) It is the same thing. FA and RHA effect is shown through follow up results in the next paragraphs.

Table 4.6: Chemical composition of GGBS

Chemical analysis	Weight %	MS 1387: 1995 of GGBS %
SiO_2	29.35	35
Fe_2O_3	0.52	0.5
CaO	49.76	40
MgO	4.20	8
K_2O	0.42	0.46
SO_3	2.04	2.09
Al_2O_3	11.72	12
LOI	1.42	2.1

4.7 Superplasticizer

Sika-viscocret 1600 used in the SCC concrete chemical analysis conducted according to (ASTM, 1986, C494 / C494M) expressio reduction and excellent flowability with optimal cohesion and strong self-compacting concrete. Sika-1600 does not contain chlorides or other ingredients which promote steel corrosion; and therefore, it may be used without restriction for reinforced and pre-stressed concrete construction. Table 4.7 shows the engineering properties and chemical composition of superplasticizer. Through the results of the workability and durability, the effectiveness of this type on these properties can be understood.

Table 4.7: Engineering properties and chemical composition of superplasticizer

Attribute	ASTM C494-86
Type	Sika® Viscocrete ®-1600 – G
Color	Dark Brown Liquid
Storage Conditions	Between +5°C and +30°C.
Chemical Base	Aqueous Solution Of Modified Polycarboxylate Copolymers
Density	1.09 ± 0.02
Dosage	Dosage for Concrete SCC 0.5 – 2.0% By Weight Of Cement

4.7.1 Effect of superplasticizer dosage

According to Okamura´s method for self-compacting concrete mix design, the dosage of superplasticizer was first determined in mortar mixtures and was then adjusted in concrete mix trials (Okamura & Ouchi, 2003). In this study, different dosages of superplasticizer were used and the water binder ratio was adjusted to get the best concrete mix with high workability, no segregation occurred in the mix. Table 4.8 and Figures 4.4 to 4.7 show the proportioning and workability properties of SCC with different dosages of superplasticizer. Based on the strength target (40) MPa and workability properties, 1.0% percent superplasticizer was chosen for in this study. Moreover, the use of superplasticizer with higher or lower percentage may only produce undesired results (Table 4.8), which are confirmed in Figure 4.3.

The Sika® Visco-crete ®-1600 – G used together with SCC to resist salts according to Safiuddin (2008) testing for self-compacting concrete, the ingress of sulfate ions in SCC is impeded due to reduced porosity and depressed transport properties.

Table 4.8: Mix properties of different superplasticizer dosage in SCC at 28 days

Mix. No	W/b	S.P (%) of binders	Slump flow (mm)	T_{50cm} (sec)	V Funnel flow (sec)	Compressive strength (MPa)
SCCOPC1	0.53	1	630	6	9	40
SCCOPC2	0.53	1.5	600	9	11	43
SCCOPC3	0.53	2	690	5	6	46

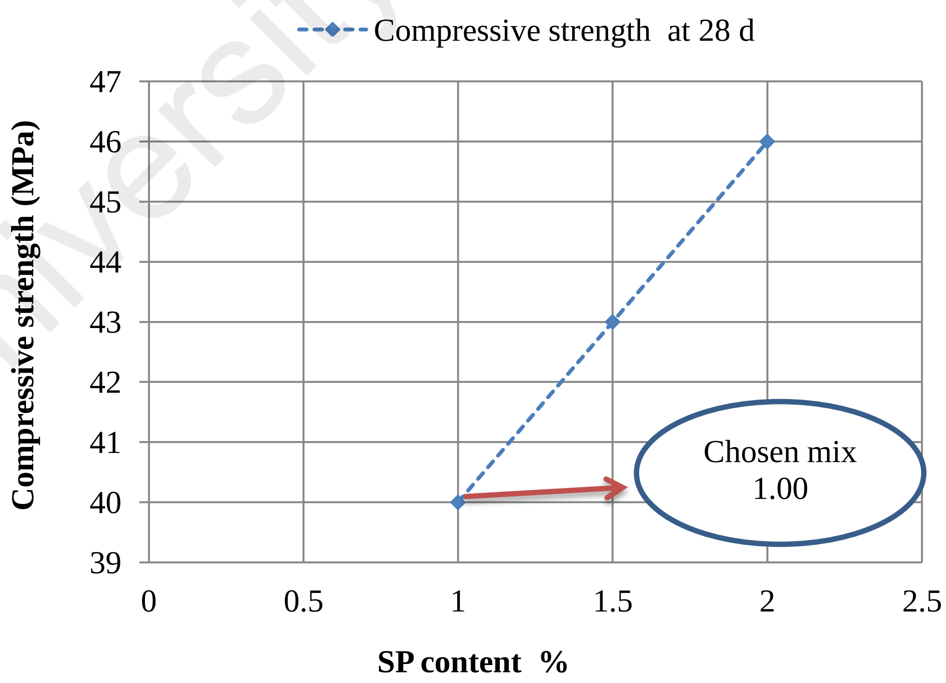

Figure 4.3: Effect of superplasticizer content on compressive strength of SCC

The workability of SCC (1), SCC (2) and SCC (3) in different supersteplesizer dosages (Figures 4.4 to 4.6) shows that SCC (1) meets the desired criteria. With compressive strength of 40 MPa the slump flow is 630 mm, V funnel flow is 9 sec and T_{50cm} is 6 sec. These results is similar to the limitations of European standard guidelines for self-compacting concrete specification (ERMCO, 2005)

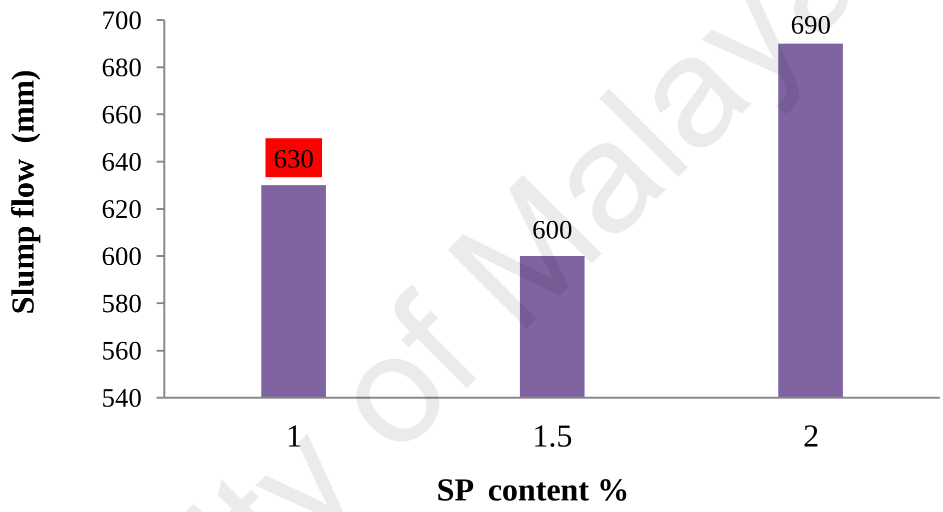

Figure 4.4: Effect of superplasticizer ratio on slump flow of SCC

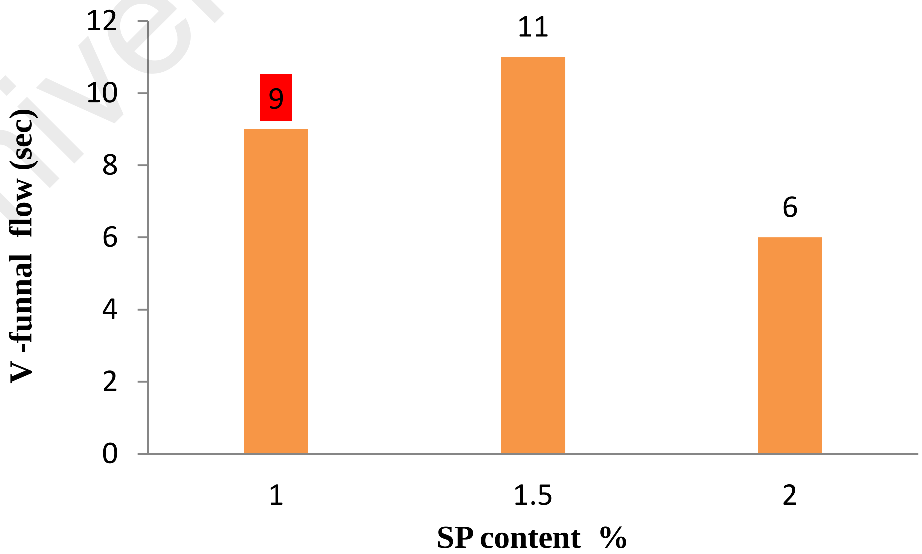

Figure 4.5: Effect of superplasticizer ratio on V funnel flow

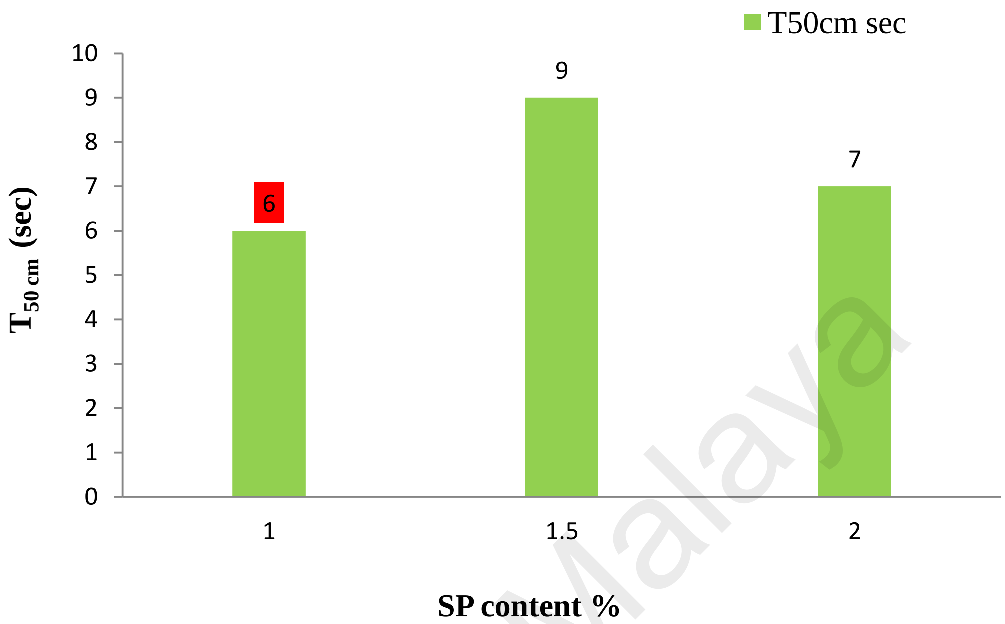

Figure 4.6: Effect of superplasticizer content on T_{50cm} of SCC

4.8 Mix proportions of SCC

4.8.1 Effect of aggregate ratio on SCC

Three mixes were tested to evaluate the effect of aggregate ratio of coarse to fine on strength properties of SCC. The aggregate ratios used were 60/40, 55/45, and 50/50. The results and property of SCC concrete such as strength and workability of these three mixes are shown in Figures 4.7 and 4.8 and presented in Table 4.9.

The compressive strength shows that normally, the amount of cement required is less when the aggregate ratio used is 40/60. Furthermore, the workability problem which occurred when 50/50 aggregate is used can be avoided by using the ratio of 55/45.

The use of 50/50 aggregate ratio increases the proportion of the coarse aggregates, and consequently, increases the surface area of the aggregates. The requirement in using fine aggregate to cover the surface area will also increase and lead to the inability to control strength and workability concrete as well as segregation between aggregates and mortar. This means 55/45 aggregate ratio produces a higher strength compared to the other aggregate ratios. When the aggregate ratio increased from 40/60 to 50/50 the strength of the concrete decreased. The experiments showed that the best mixing ratio of SCC is 55/45 because any increase over this mixing range of coarseness will result and reduction of the strength and workability the concrete. Results shown in Table 4.9 is in accordance with European Standard Guidelines for Self-compacting Concrete Specification (ERMCO, 2005).

That the largest fraction in concrete is aggregates which affect the compressive strength and properties of the concrete (Zhang and Gjorv 1991) the effects of the aggregate ratio on the strength and workability are shows in Table 4.9.

Table 4.9: Mix properties for the aggregate ratio of SCC

Mix .No	W/b	Cement (Kg/m^3)	Fine-ag (Kg/m^3)	C.A (Kg/m^3)	Water (Kg/m^3)	SP% of binder	Slump flow (mm)	Compressive strength 28 d (MPa)
SCC (55-45)	0.53	406	895	732	215	2	630	41
SCC (60-40)	0.53	406	1002	670	215	2	610	45
SCC(50-50)	0.53	406	837	837	215	2	500	47

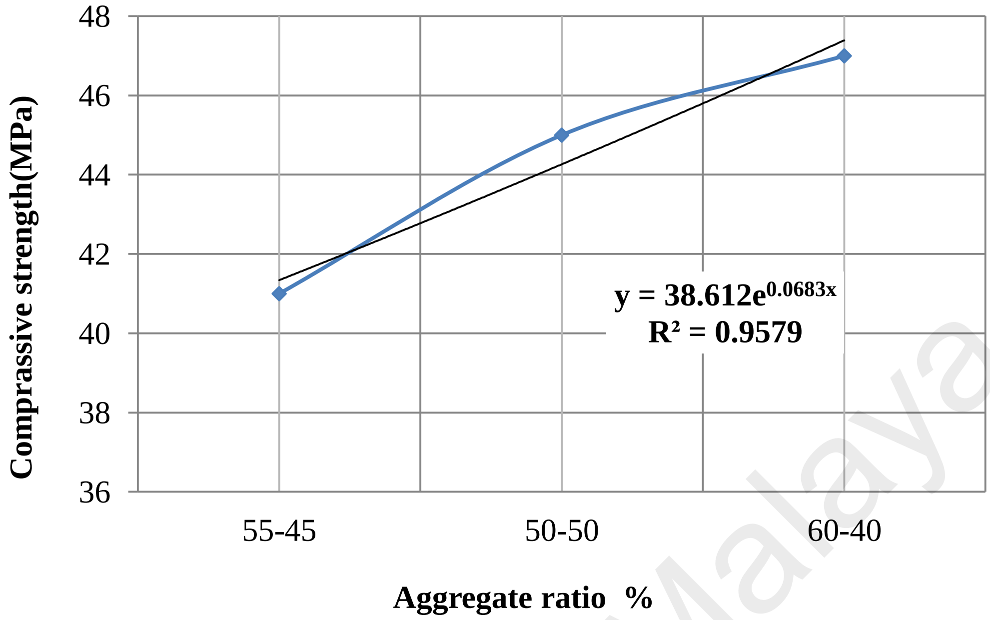

Figure 4.7: Effect of aggregate ratio on compressive strength of SCC at 28 days

In Figure 4.8, the highest slump flow (650 mm) by the aggregate ratio of 55/45 indicates that the mix is similar to the European guidelines for self compacting concrete specification (ERMCO, 2005)

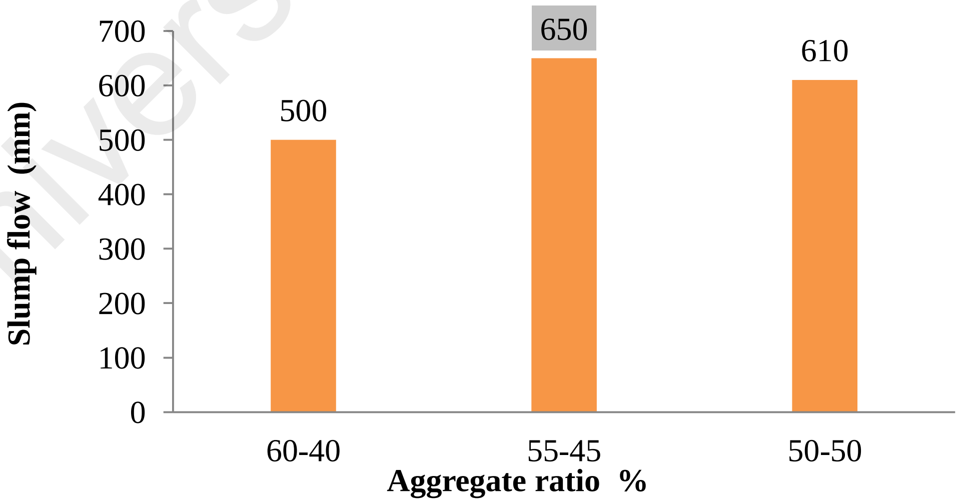

Figure 4.8: Effect of aggregate ratio on slump flow of SCC

4.8.2 Effect of different cement content on SCC

Different percentages of cement content (440, 432, and 406 kg) were used with the SCC. The engineering properties and workability results are presented and discussed in the following paragraphs.

A few problems arise when was used the cement content 406. First, the maximum size of aggregate used should not be more than 14 mm for better flowability; secondly; cement absorbs the water rapidly to complete its interaction. Therefore, the workability of the concrete will be increased accordingly, and the compressive strength will be the higher among the three mixes.

This is because the surface area of aggregates very big and that requires more cement to cover the area. In addition, it augmented the absorption of cement and aggregates as well as the workability and strength concrete. In this study, cement content of mix SCCOPC3 met the requirements of workability and strength grade, which is 40 MPa. The experimental studies showed the strength increased with increases in cement content.

The performance of concrete is also a function of cement content. The cement content in the SCC mix is in the range of 280 to 557 kg /m^3 (ACI, 363,1992). Table 4.10 and Figure 4.9 showed the cement content of 406 kg that met the desired workability and strength.

Table 4.10: Mix properties of SCCOPC with various cement content

Mix .No	W/b	Cement content (Kg)	Slump flow (mm)	T_{50cm} (sec)	SP % of binder	Compressive strength (MPa)	
						7d	28d
SCCOPC1	0.53	440	580	8	2	35	46
SCCOPC2	0.53	432	640	7	2	30	44
SCCOPC3	0.53	406	650	5	2	36	43

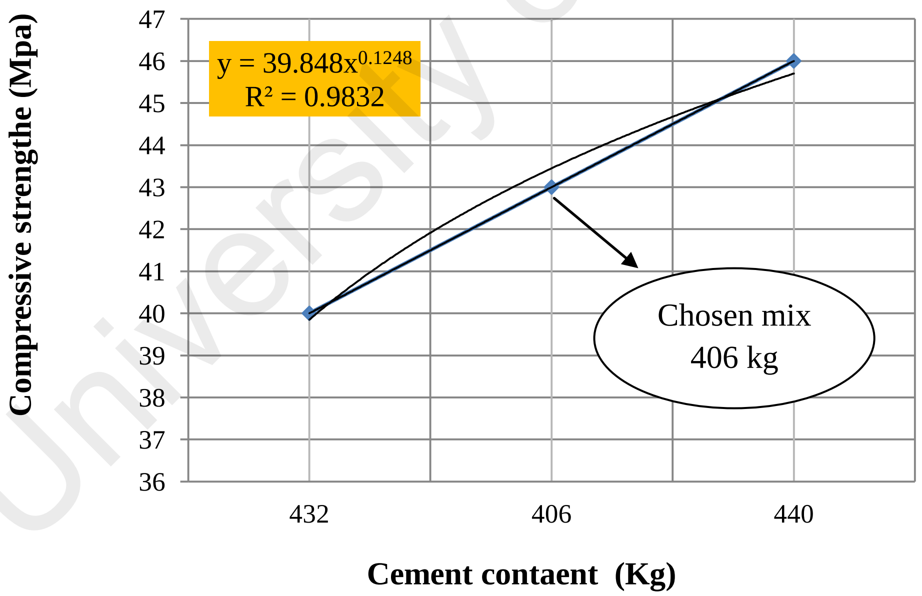

Figure 4.9: Effect of cement content on compressive strength of SCCOPC mix

4.8.3 Effect of FA content on SCC mixes

FA was found to be the traditional material to be used in controlling the segregation potential and deformability of fresh SCC. Three mixes were tested to evaluate the percentage effect of fly ash on the strength property of SCC. The best ratio used with SCC was 15% to obtain strength grade of 40 MPa. Because a lot of researchers use a higher percentage of FA, they have faced difficulties in balancing the engineering properties and the workability. According to Khurana and Saccone (2001), using fly ash can save cost because FA can augment the slump of concrete mixture with no additional cost, lessen the need for cement, fine fillers and sand required in SSC. In this study, the experiment done on 15% of FA showed that it met the requirements and results of the strength and of fresh properties. These three SCC mixes are shown in Table 4.11 and Figure 4.10

Table 4.11: Mix properties of SCCFA mix with different FA content

Mix .No	W/b	FA (Kg)	SP% of binder	Slump flow (mm)	T_{50cm} (sec)	Compressive strength (MPa)	
						7d	28d
SCCFA5	0.53	18	1	690	8	39	49
SCCFA10	0.53	38	1	600	9	38	50
SCCFA15	0.53	58	1	630	6	33	45

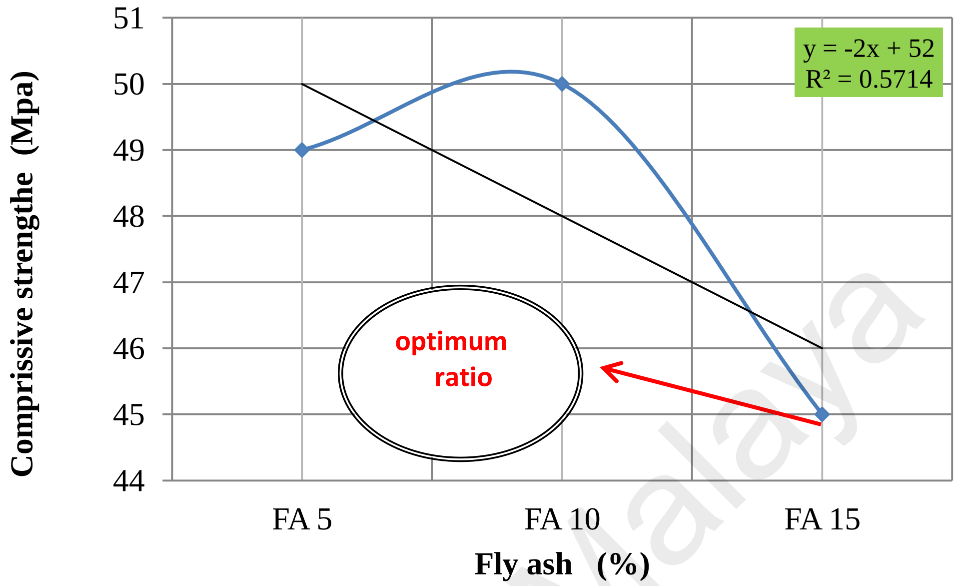

Figure 4.10: Effect of fly ash content on compressive strength of SCC

4.8.4 Effect of RHA content on SCC mixes

Three mixes were casted to evaluate the effects of RHA of 5%, 10% and 15% content on mechanical properties and the workability properties of SCC. In this study, the proportion of 10% rice husk ash was the optimum in order to get the best strength within the limits of 40 MPa according the Strength Reduction Factors SRF. This is because, higher content of rice ash cause the pozzolanic materials and concrete strength to increase and thus, allow us to get the desired strength (40) as shown in Table 4.12 and Figure 4.11. Integration of pozzolanic materials with cement causes the cement to hydrate and released calcium hydroxide that will react with silica in the pozzolanic material. This will form additional calcium silicate hydrate (C-S-H), which improve the strength concrete (Mehta, 1996) Again, the desired requirement of strength and workability was achieved at 10% RHA.

Table 4.12: Effect of RHA content on SCC mixes

Mix .No	W/b	RHA (Kg)	SP% of binder	Slump flow (mm)	T_{50cm} (sec)	Compressive strength (MPa)	
						7d	28d
SCCRHA15	0.53	58	1	600	7	47	52
SCCRHA10	0.53	38	1	600	6	32	45
SCCRHA5	0.53	18	1	600	8	34	41

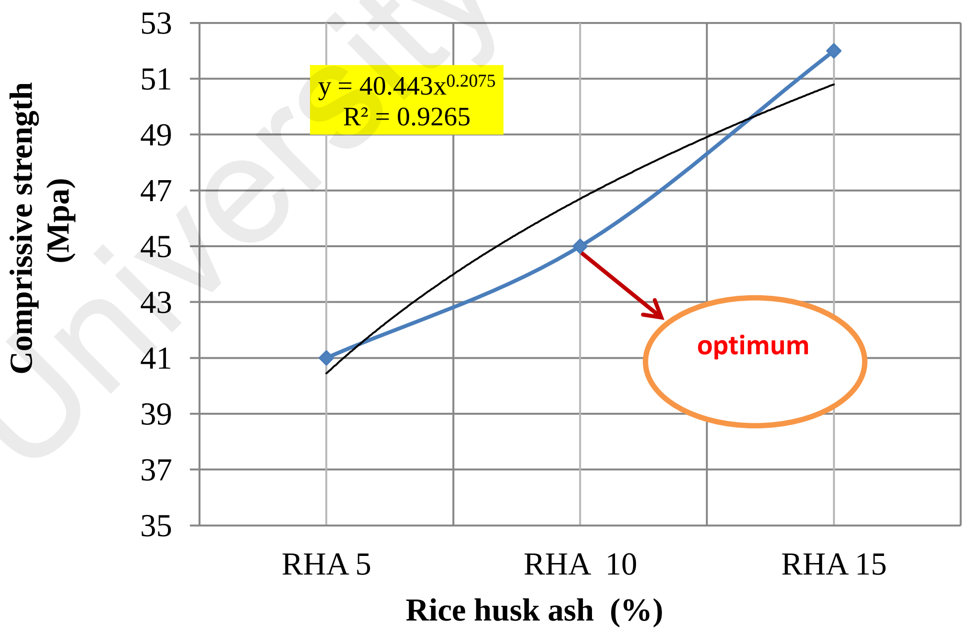

Figure 4.11: Effect of RHA content on compressive strength of SCCRHA

4.8.5 Effect of GGBS on SCC mixes

Three concrete mixes with different percentages of GGBS replacement (5%, 10% and 15%); each having the same water binder ratio of 0.53 were tested in this study. The self compatibility of the mixes was maintained by adjusting the superplasticizer dosage. The designations of the specimens and mix proportions are presented in Table 4.13 Anything above 5% gives a concrete grade of 40 MPa and an improvement in the strength and workability of self-compacting concrete. Therefore, the selected percentage used in this study confirms the required standard of strength and workability.

Table 4.13: Mix properties for the SCCGGBS

Mix .No	W/b	GGBS (Kg)	SP %	Slump flow (mm)	T_{50cm} (sec)	Compressive strength (MPa)	
						7d	28d
SCCGGBS5	0.53	18	1	690	4	36	43
SCCGGBS10	0.53	38	1	600	6	40	47
SCCGGBS15	0.53	58	1	650	4	39	55

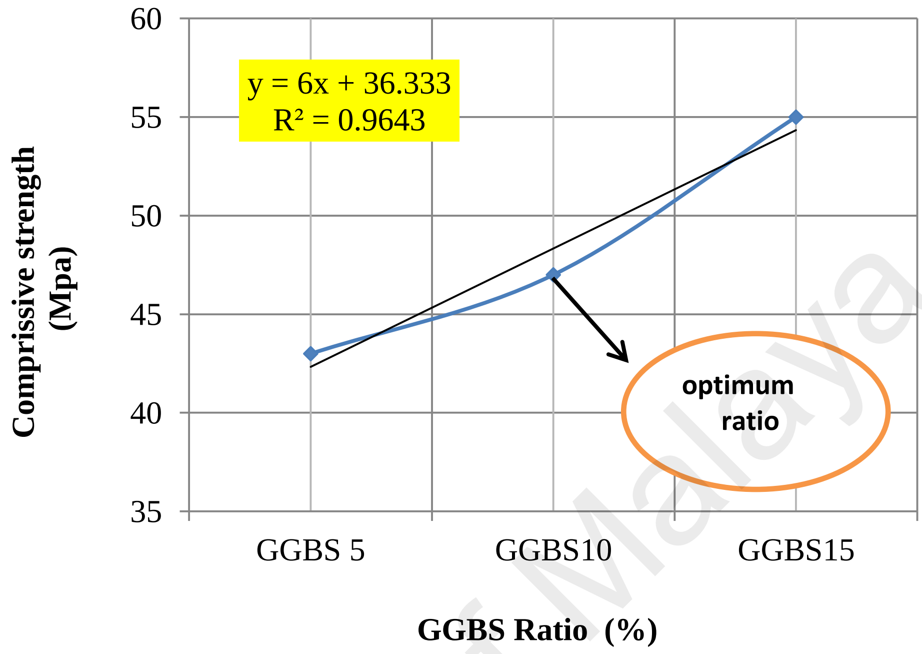

Figure 4.12: Effect of GGBS content on compressive strength of SCC

4.8.6 Chosen the mix proportion

In this work, four parameters have been investigated: self compacting concrete with three OPC mixes, different quantity of cement has been used and self compacting concrete with FA, self compacting concrete with RHA, and self compacting concrete with GGBS. Details of these experiments are described in the next section. Three different percentages of FA were used in the FA concrete mixes. In RHA and GGBS, replacement at three percentages has been utilized. Details of the above mentioned experimental works can be seen in Table 4.14 and Figure 4.13 which explain the mix proportions of SCC with various percentages of supplementary cementitious materials such as FA, RHA, and GGBS.

Experimental results achieved with concrete resistance of 40 MPa and other test including the slump flow, V funnel flow and T_{50cm} conform to the European guidelines for self compacting concrete specification (ERMCO, 2005)

Table 4.14: Selected mix proportions of SCC pear m^3.

Mix .No	W/b	Cement (kg)	F.A (kg)	C.A (kg)	Water (kg)	S.P. % of binder	Pozzolanic materials (kg)
SCCOPC1	0.50	440	916	750	220	1	0
SCCOPC2	0.52	432	900	679	225	1	0
SCCOPC3	0.53	406	895	732	215	1	0
SCCFA5	0.53	388	895	732	215	2	18
SCCFA10	0.53	368	895	732	215	1.9	38
SCCFA15	0.53	349	895	732	215	1.8	57
SCCRHA5	0.53	388	895	732	215	1.8	18
SCCRHA10	0.53	368	895	732	215	1.7	38
SCCRHA15	0.53	349	895	732	215	1.6	57
SCCGGBS5	0.53	388	895	732	215	1.9	18
SCCGGBS10	0.53	368	895	732	215	1.8	38
SCCGGBS15	0.53	349	895	732	215	1.7	57

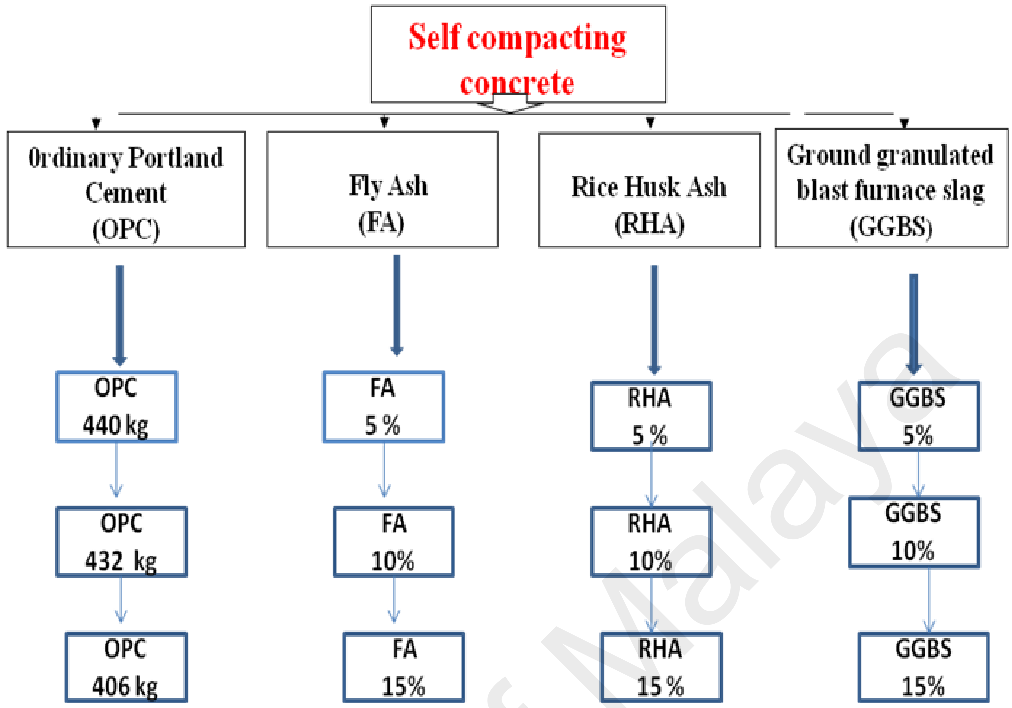

Figure 4.13: Mix proportions of mixtures containing various ratio of SCM on SCC

4.9 Workability of fresh SCC containing SCM

To characterize the properties of SCC, FA, RHA and GGBS, no single method has been found to date which characterizes all of the relevant workability aspects, and therefore, each mix has been tested by more than one test method for the different workability parameters. Presents workability of SCC is measured by slump flow and the normal slump, and the basic equipment used is the same as for the conventional slump test. Testing for normal slump flow for conventional concrete over the SCC because the sample will collapse when the slump cone is removed if there is no reinforcement rod placed in the mould. V funnel flow is other test that is taken into account for the filling capacity and flowability time T_{50cm}.

It is a secondary indication of measurement or flow that indicates the tendency for segregation, wherein the funnel can be refilled with concrete and left for 5 minutes to settle. The L Box test measures the height of the concrete at both ends. The L-box test can give an indication as to the filling ability and passing ability. Self compacting concrete reduce the labor in the replacement of concrete by eliminating or reducing the need for vibration to achieve consolidation .Therefore, the main property that defines SCC is high workability in attaining consolidation and specified hardened properties (Ferraris, 2000,et al). Finally, the slump flow and the normal slump are not enough to determine the flowability of SCC, and that means that other tests are required in order to get the various properties of workability of SCC. Table 4.15 presents all results of the workability tests.

Table 4.15: Results of workability tests of SCC

Mix-No	Filling ability			Passing ability		
	V funnel flow (sec)	$T_{50\ cm}$ (sec)	Slump flow (mm)	L Box %	Segregation %	J Ring (mm)
SCCOPC	5	4	610	85	4%	8
SCCFA15	7	5	610	89	6%	10
SCCRHA10	9	5	630	81	7%	9
SCCGGBS5	11	6	650	82	15%	8

4.9.1 Filling ability

Filling ability, or flowability, is the ability of the concrete to completely flow (horizontally and vertically upwards if necessary) and fill all spaces in the formwork without addition of any external compaction. The flowability of SCC is characterized by the concrete's fluidity and cohesion and is often assessed using the slump flow test.

4.9.1.1 Slump flow & T_{500mm} flowability test

The basic equipment used is the same as for the conventional slump test (EFNARC, 2002). The diameter of the spread of the sample is measured; a horizontal distance is measured as against the vertical slump measured in the conventional test

In this study, the effects of fineness and particle size on supplementary cementious materials are shown in Figure 4.14. As depicted, a higher slump flow is achieved by GGBS-containing mixes. This is because, the larger the fineness, the aggregates contents are also increased and cause high flowability. However, the aggregates contents will decrease and increase the slump flow when paste content increase (Safiuddin, 2008). Figure 4.15 depicts the results of selected SCC including the standard limit of it.

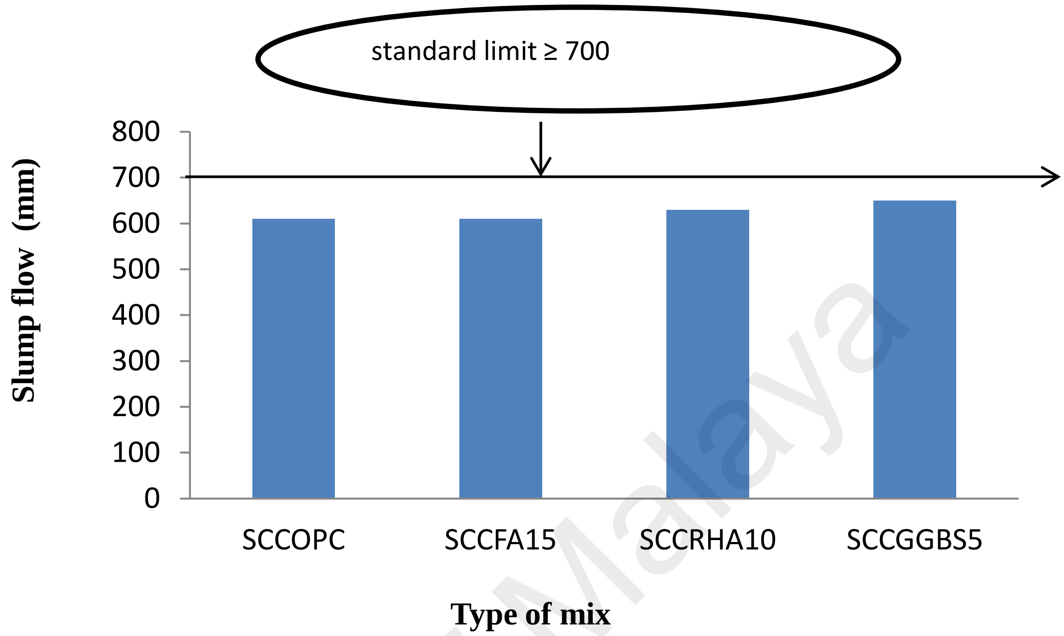

Figure 4.14: Relationship between slump flow and mix type of SCC.

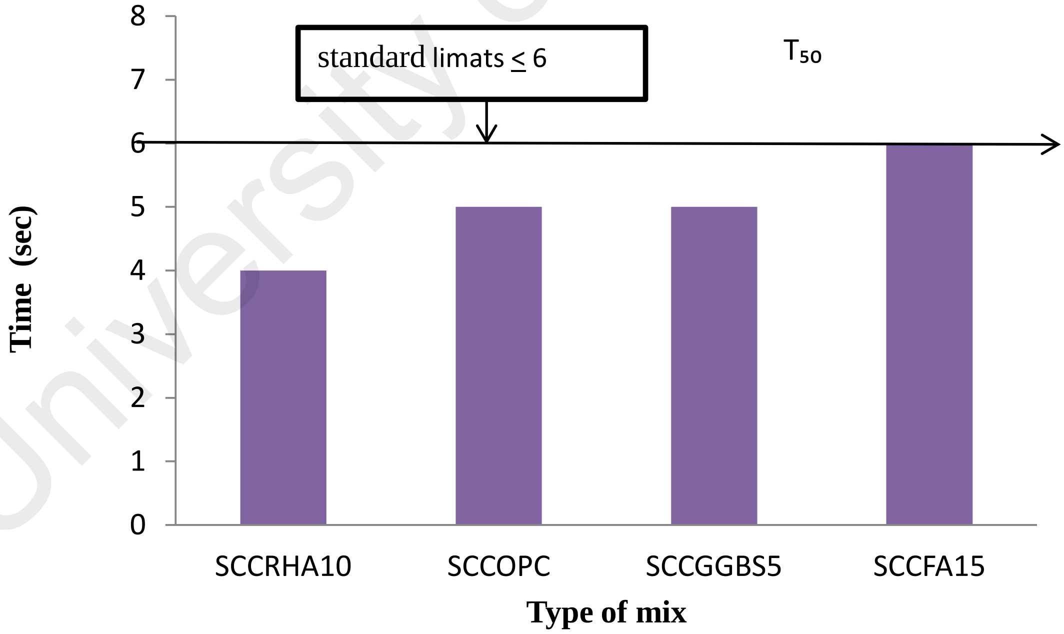

Figure 4.15: Relationship between T_{50}cm test and type of mix SCC

4.9.1.2 V funnel flow test

Though the test is designed to measure flowability, the result is affected by concrete properties other than flow. The V funnel is filled with concrete and the time taken by it to flow through the apparatus measured. This test gives account of the filling capacity (flowability).

Figure 4.16 presents the results of workability tests, conducted to achieve self-compacting concrete. The trials were started at 55 percent volume of total concrete as content of coarse aggregates and 45 percent by volume of mortar in concrete as contents of fine aggregates and variation in w/p ratio and superplasticizer was carried out to achieve SCC mixes. In case of further trials, the coarse aggregate content and fine aggregate content were varied with further variation in water/cement ratio.

Findings of this study show that OPC-containing mix has less flow time compared with other mixes followed by FA, RHA and GGBS. This is because OPC-containing mix has less binder ratio. For FA, higher possibility of passage is due to the spherical shape of it. all results on specification limit of self compacting concrete according to guide specifications or self compacting concrete (EFNARC, 2002) Generally, V funnel flow is affected by the amount binders and shape of particle. Sahmaran (2006) fly ash and limestone powder is among the mineral additives that can significantly increase the workability.

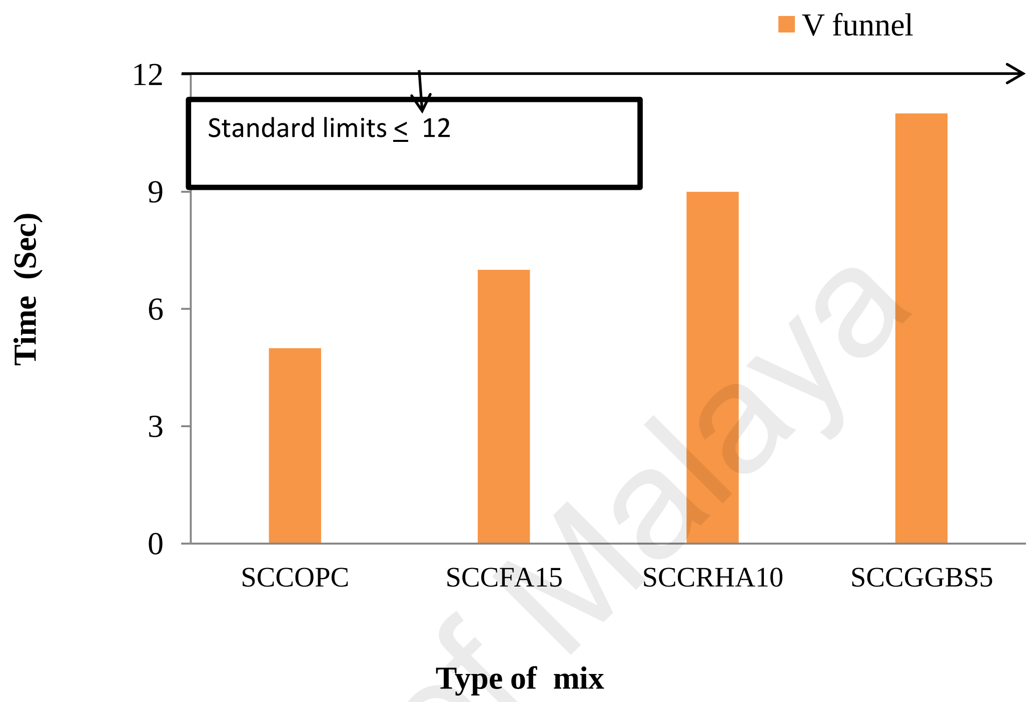

Figure 4.16: Relationship between V funnel flow test and mix type of SCC

4.9.2 Passing ability

Passing ability is the ability of the concrete to flow through restricted spaces without blocking them. This property is related to the maximum aggregate size and aggregate volume, and the L-Box test is the most common method used to assess this property.

4.9.2.1 L Box Test

The L-box test method uses a test apparatus comprising of a vertical section and a horizontal trough into which the concrete is allowed to flow on the release of a trap door from the vertical section, (See. Fig 3.13) passing through reinforcing bars placed at the intersection of the two areas of the apparatus (Peterson at el, 1996). The concrete ends of the apparatus H1 and H2 measure the height of the concrete at both ends. The L-box test can give an indication as to the filling ability and passing ability.

The specification guide on self-compacting concrete requires various mixtures of FA, RHA, and GGBS with SCC to satisfy the standard limits of L Box test (EFNARC, 2002). Figure 4.17 illustrate the results of L-Box test. This test is conducted to understand the effect of pozzolanic material on SCC. As illustrated, the defferent in higher ΔH shown is higher in GGBS and FA than in RHA and OPC. This is because both GGBS and FA have higher fineness content than the other two. According to Maghsoudi et al. (2007), by having a high mixed designed, some aggregate will be replaced by powder material to keep the water content so the properties of the fresh concrete can be known.

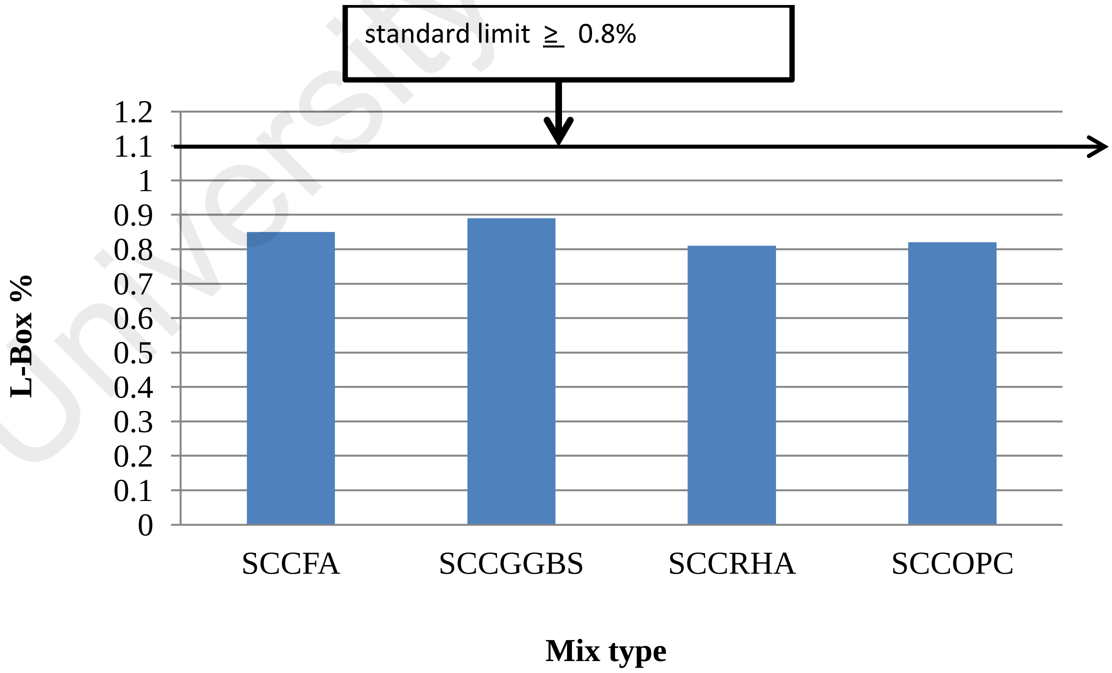

Figure 4.17: L-box test and mix type of SCC

4.9.2.2 J Ring test

This involves the slump cone being placed inside a 300 mm diameter steel ring attached to vertical reinforcing bars at appropriate spacing (Figure 3.14) (Bartos, 2000) as in the slump flow test, the diameter of the spread and the T-50 time are recorded, and the height of the concrete after the test within the J-ring was also measured. The Slump flow/J-ring combination test is an improvement upon the slump flow test on its own as it also aims to assess the passing ability of the fresh mix.

In this study, effect of SCM on passing ability of the four mixes through steel bar to asses J-ring test. Results in Figure 4.18 show that the passing ability of SCCFA is the best compared to other SCC. This is because the spherical shape of FA cause it easily rolls over one another (Topçu, 2010).

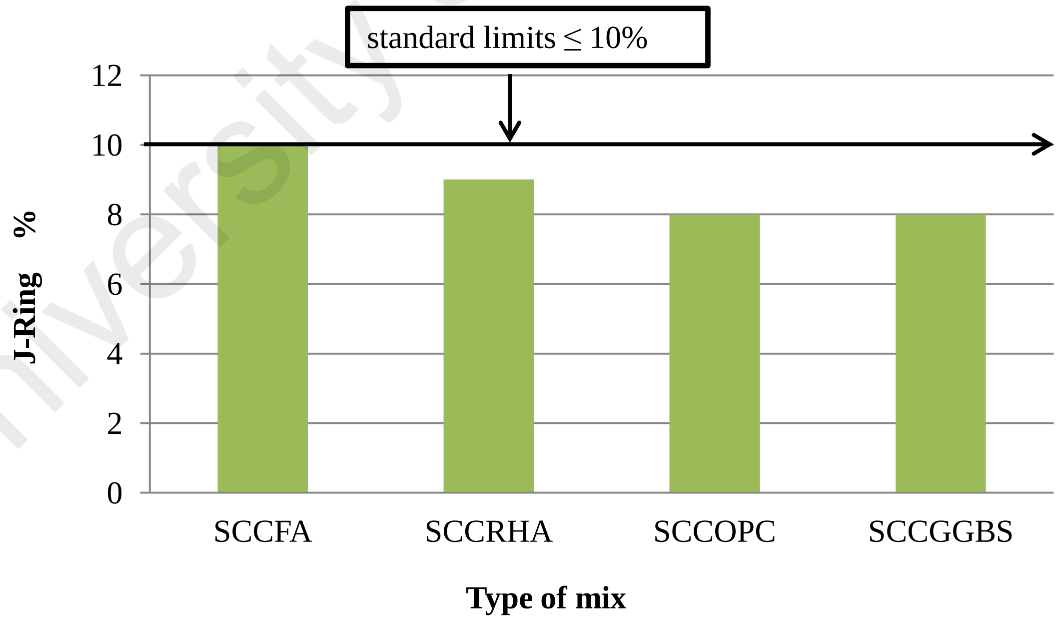

Figure 4.18: Relationship between J-Ring test and mixing type of SCC

4.9.3 Segregation of fresh SCC

According to the specification, SCC with different SCM such as FA, RHA and GGBS on the European 2005 standard limit of concrete was used.

The process of segregation in the self-compacting concrete is one of the main problems in this type of concrete, and this happens for two reasons: the first is because there is no control of the percentage of superplasticizer in the concrete, and is increase in proportion of coarse aggregate and the second reason as a result of lack of control over the proportion of W/b ratio in the mixtures led to increased segregation between the components of the mixture and that what has been overcome in this study by adjusting the proportion of the SCM mix, the concrete can be free of segregation and it was what obtained in this study. Moreover, FA ad RHA showed growth in resistance segregation compared to OPC and GGBS (Figure 4.19). This is due to the effect of water to binder ratio where higher water to binder ratio can lead to homogeneous mixing and thus reduce the segregation.

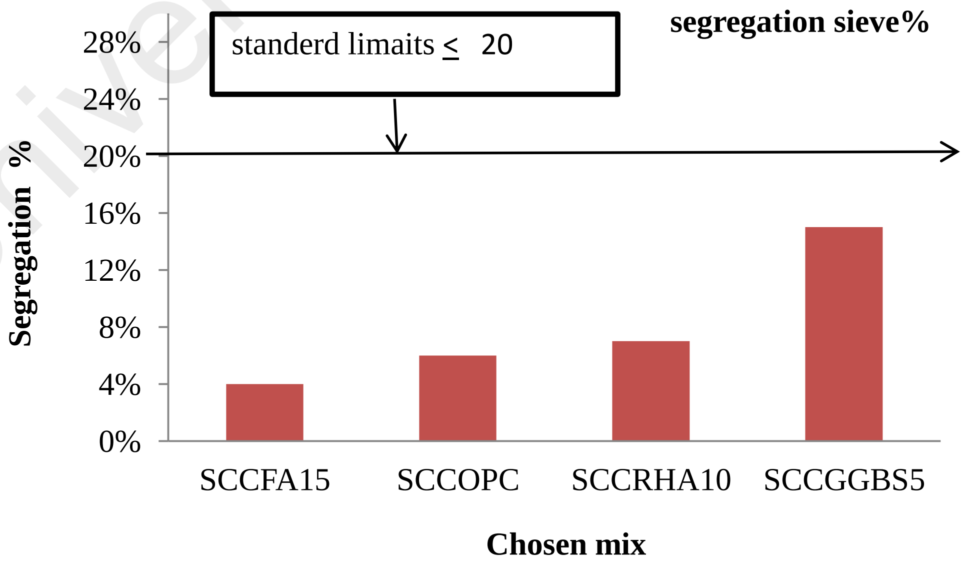

Figure 4.19: Effect of various mixes containing SCM on segregation

4.10 Mechanical properties of hardened SCC with SCM

The mechanical properties of SCC on compressive strength, flexural strength, splitting strength, modulus elasticity, creep, and strain shrinkage is described in detail in the following sub-sections.

4.10.1 Compressive strength

4.10.1.1 Effect of SCM on the compressive strength

The effect of SCM on the compressive strength of self compacting concrete with different percentages of selected SCM (FA, RHA and GGBS) to different curing ages is presented in Table 4.16 and Figure 4.20. This figure indicates that compressive

Strength corresponds with the requirement of SCC at 28 days and can also show enhancement of the strength at more than 40 MPa, at the later ages of concrete strength but it is within the range for target strength using these additional materials.

One thing that is noticeable is the high early compressive strength of FA. Such concrete type normally have a slower strength development because of the lower hydration rate of the fly ash. Therefore, it is difficult to compare the compressive strength with conventional concrete at 28 days (Thienel, et al , 2005)

4.10.1.2 Effect of curing tank on compressive strength

In this study, the specimens were tested at different ages from 7 to 360 days for compressive strength determination. The results are shown in Figure 4.20. This figure and Table 4.16 also show that the SCC mixtures using the SCM exhibited higher compressive strength than normal self compacting concrete after 2 years.

The difference is around 39% for FA15, 22% for RHA10 and 10% GGBS5 compared to control SCCOPC mix and compared to normal concrete compressive strength. However, mixes containing RHA, FA and GGBS indicate higher compressive strength until 660 days rather than samples with no replacement, because increasing the rate of pozzolanic reaction of the SCM in the matrix increases the strength of the composite mixes. Pozzolans from industrial and agricultural by-products such as FA, RHA and GGBS are receiving more attention now since their usage generally improves the properties of the blended concrete (Madandoust, et al,2011)

Table 4.16: Compressive strength of SCC with FA, RHA, and GGBS at various curing ages

Mix. No	W/b	Compressive strength (MPa)					
		7 d	28 d	90 d	180 d	360 d	660 d
SCCOPC	0.53	34	44	50	50	51	53
SCCFA15	0.53	38	46	59	69	71	74
SCCRHA10	0.53	33	41	44	47	57	62
SCCGGBS5	0.53	28	40	43	45	55	58

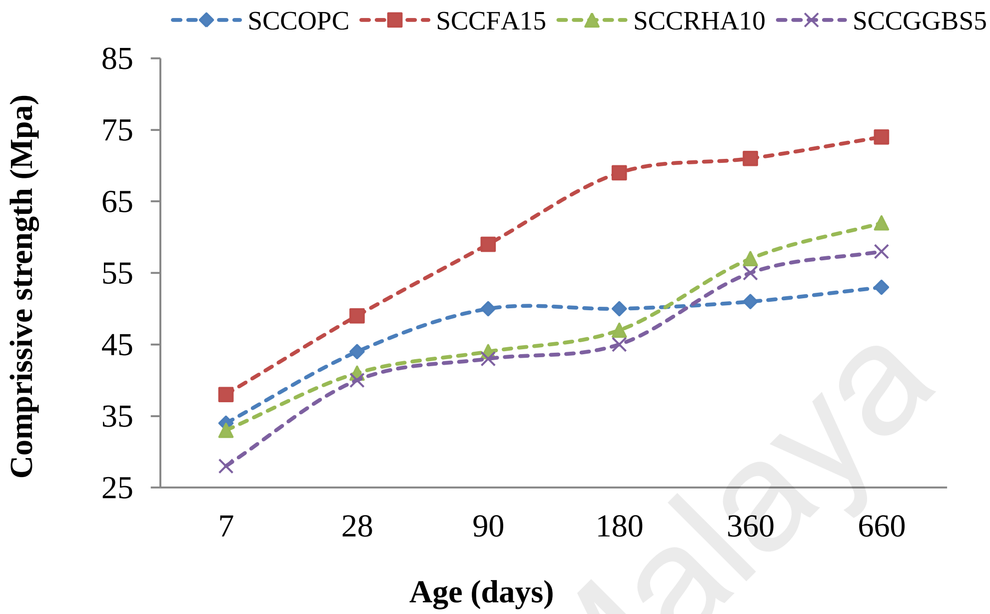

Figure 4.20: Effect of curing age on compressive strength of SCC containing SCM

From the results also, the FA show higher strength compared with RHA and GGBS due to the shape, silica ratio and particle size. It is indeed because of the factors that the strength of FA can be developed. Results for the comparison of other research on the same SCM used are tabulated in Table 4.17. The comparison showed that there is growth of strength for the mix proportions used in this study, and it is agreed with other studies that also used high volume of FA. Other supplementary cementitious materials to produce more sustainable and durable concrete (Malhotra, 1999)

Table 4.17: Comparison present strength results with other researchers

Others	Additives materials SCM %			Compressive strength (MPa)		
	FA	RHA	GGBS	FA	RHA	GGBS
Aiad , 2013	15	10	5	49	41	40
Habeeb, 2010		20			42	
Kartini, ICCBT 2008- NC		20			30	
Mahmud-JACT		10-20			64	
Ahmad ICCBT 2008-NC	15			47		
Resheidat-ICCBT-208 SCC	10			52		

4.10.1.3 Strength reduction factor of SCC with various SCM ratios

From prior information, the strength characteristic of the concrete obviously depends on the SCC. This is further investigated using an analytical technique. The property of the concretes strength reduction factor (SRF) is defined as the ratio of the compressive strength of concrete containing FA, RHA and GGBS to the compressive strength of the control SCC.

This is expressed mathematically in equation 4.1. A similar definition was found in the literature for tire-rubber concrete (ACI & 1995).

$$\mathrm{SRF} = \frac{\text{(Strength of concrete containing FA, RHA, GGBS)}}{\text{Strengh of control SCC}} \qquad 4.1$$

Compressive strength results were used at 28 days to calculate SRF using Eq. 4.1. Thus, the SRF obtained were 1.09, 1.14, 1.02 for 15% FA; 1.07, 1.02, 0.93 for .RHA and 0.98, 1.02, 0.93 for GGBS mixtures. Here, the SRF is used to calculate the reduction in compressive strength. It is shown that for 15% FA the SRF decreases 5% to be almost the same strength when 5% FA is applied. The same trend goes for GGBS mix but not for RHA, which increases with the increasing of RHA content. However, the results showed the ratio of SCM is the best ratio obtained for the SCC grade 40 MPa (Table 4.18 and Figure 4.21).

The variable space domain of SCM is classified into two subdivisions: greater than 5% SCM and less than 15% SCM. By using Eq. 4.2, SRF for FA increases with a rise in admixture contents and augment the SCM content to 15%. The same goes to SRF for RHA and GGBS.

$$SRF = \begin{cases} 0.12\ p + 1, & if\ SCM \leq 15\% \\ -0.51\ p + 1.14, & if\ SCM \geq 5\% \end{cases} \qquad 4.2$$

p = powder content, (Kg/m^3)

SCM= supplementary cementitious materials

A graphical representation of SRF against SCM content is shown in Figure 4.21.

Table 4.18: Strength reduction factor versus NSCC with various SCM at 28 days

Mix. No	W/b	Compressive strength of SCM (MPa)			Compressive strength of NSCC (MPa)	SRF %		
		5%	10%	15%	28 days	5%	10%	15%
SCCFA15	0.53	48	50	45	44	1.09	1.14	1.02
SCCRHA10	0.53	47	45	41	44	1.07	1.02	0.93
SCCGGBS5	0.53	43	45	41	44	0.98	1.02	0.93

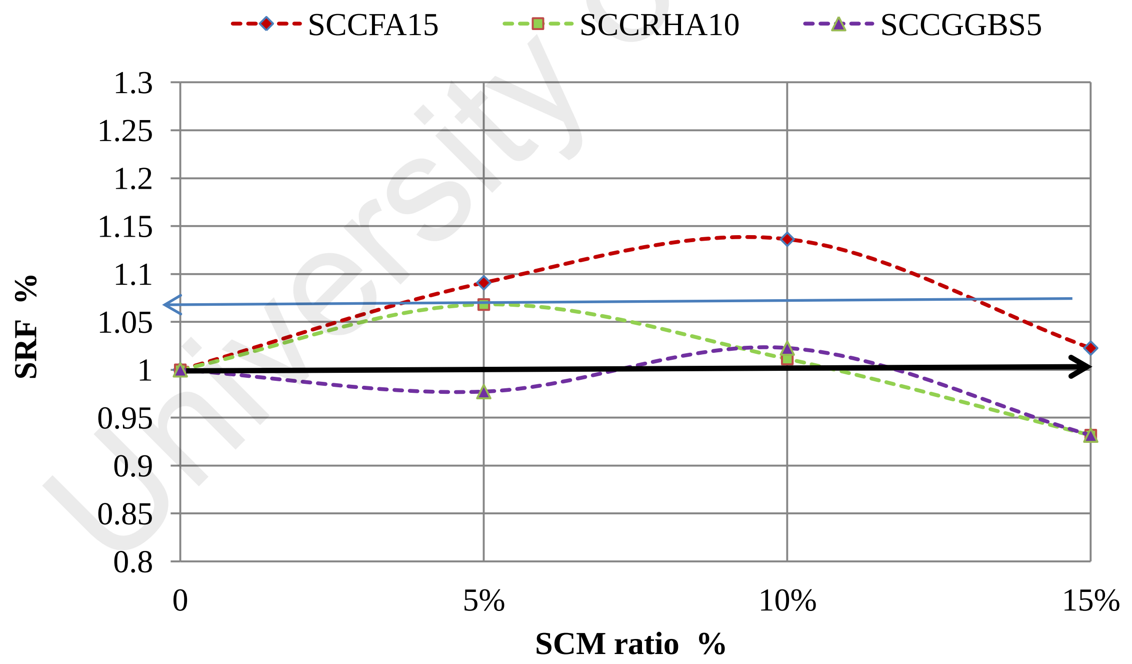

Figure 4.21: Effect of SCC containing various SCM on SRF

4.10.1.4 Relationship between modulus of elasticity and compressive strength

Used of SCM such as FA, RHA and GGBS on the compressive strength and modulus elasticity of SCC grade 40 at two ages, 28 and 180, are shown in Table 4.19 and Figure 4.26. The correlation coefficient indicated is high and is equal to 0.665 and 0.933 at 28 and 180 days respectively, similar to that formerly reported by(Mahmud, 2005)

Comparison of the relationship between compressive strength and elastic modulus of concrete, and BS8110 and ACI318.99 are shown in Figure 4.22. The figure also depicts the interrelation among the three where one increment also causes another to increase. Experimental data from three SCM (FA, RHA, and GGBS) is considered in deriving equation to explain the relationship.

$Ec = 16.6\, f_{cu}^{\ 0.15}$ (Present work) - SCCOPC 4.3

$Ec = 9.1\, f_{cu}^{0.33}$ (BS8110) - OPC 4.4

$Ec = 4.23\, f_{cu}^{\ 0.05}$ (ACI 318- 99) - OPC 4.5

Table 4.19: Modulus of elasticity and compressive strength of SCC mixes

Mix. No	W/b	Modulus elasticity (GPa)			Compressive strength (MPa)		
		28 d	180 d	660d	28 d	180 d	660 d
SCCOPC	0.53	30	31	33	44	50	53
SCCFA15	0.53	30	32	38	49	69	74
SCCRH10	0.53	29	31.5	34	41	47	62
SCCGGBS5	0.53	29.3	30	31	40	45	58

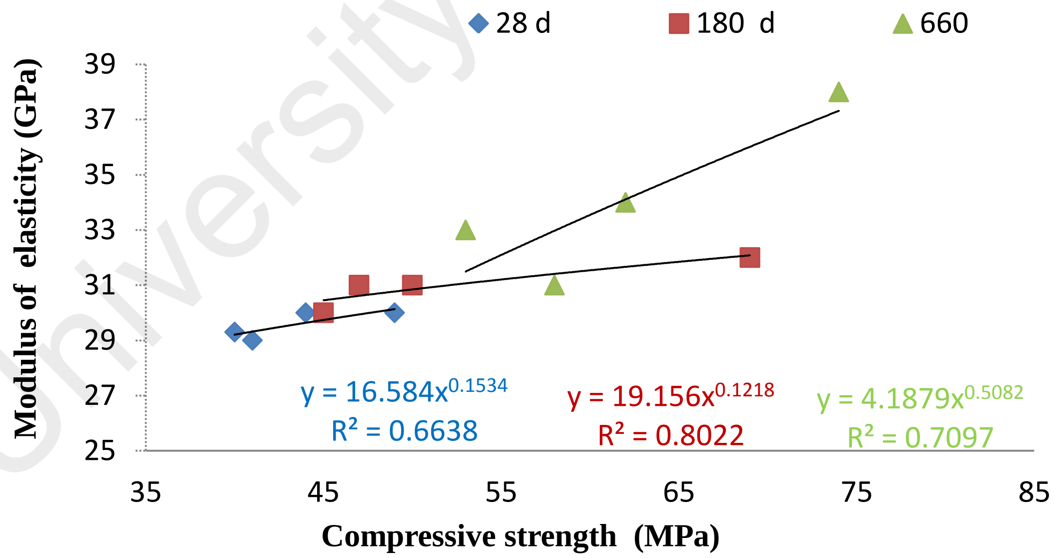

Figure 4.22: Relationship between compressive strength and modulus of elasticity of SCC

In this case, again, due to the spherical shape, silica ratio and particle size, FA gave the highest modulus elasticity compared to other pozzolanic materials (RHA and GGBS) (Table 4.20). This finding is in accordance with Berndt (2009) which stated that the strength and durability of concrete can be enhanced by supplementary cementing materials such as fly ash, silica fume and etc.

Table 4.20: Comparison between present results on modulus of elasticity and with published data

Others	SCM types			Eć (GPa)		
	FA	RHA	GGB	FA	RHA	GGBS
Present work , 2014	15%	10%	5%	32	30	30
Habeeb, Mahmud,2010	-	20%	-	-	41	-
Mahmud-JACT-(60-MPa)	-	5% -20%	-	-	26	-
Berndt (2009)	50%	-	-	37	-	-
Berndt (2009)	-	-	70%	-	-	40

4.10.1.5 Effect of curing type on compressive strength

The rate and degree of hydration and the resulting strength of concrete and other properties depended on the curing process that follows the placing and consolidation of the plastic concrete. Hydration of cement continues for years at a decreasing rate as long as the mixture contains water and the temperature conditions are favorable. Once the water is lost, hydration ceases.

Curing of mortar and concrete is very essential for their strength and to gain durability. Concrete is generally cured by water bonding (Al-Gahtani, 2010). In general, curing ensures that the correct mix of water is available for cement hydration. Through this study, two methods of curing were used to evaluate the impact on the hydration engineering properties of SCC containing SCM such as FA, RHA and GGBS on the compressive strength.

The results in Table 4.21 and Figure 4.23 showed the differences in strength of underwater curing and air drying regimes, and they showed the improvement in strength of concrete under water curing compared with air drying concrete because of the slow pozzolanic reactions between SCM and calcium hydroxide for cement hydration. Concrete needs to complete the hydration in a continuous interaction with the water curing and the acquisition of the required rigidity is important for these concretes and that the use of cement materials supporting working to react quickly and close all the pores.

ACI 308 recommended practice suggests 7 days of moist curing for most of structural concretes. However, the period of curing should be extended to 14 days when the concrete contains SCM such as slag and fly ash owing to the slow pozzolanic reactions between SCM and the calcium hydroxide for cement hydration. The process of this reaction requires the presence of water to produce the cementing compounds to contribute to the filling of the capillary voids (ACI, 1998).

Table 4.21: Effect of curing types on strength of SCC

Mix. No	Compressive strength under water curing (MPa)			Compressive strength under air drying (MPa)			water curing / air drying		
	28d	180d	360d	28d	180d	360d	28d	180d	360d
SCCOPC	44	50	51	43	42	39	1.02	1.19	1.31
SCCFA15	50	59	61	49	47	46	1.02	1.26	1.33
SCCRHA10	51	55	59	48	46	45	1.06	1.20	1.31
SCCGGBS5	47	49	57	45	42	41	1.04	1.17	1.39

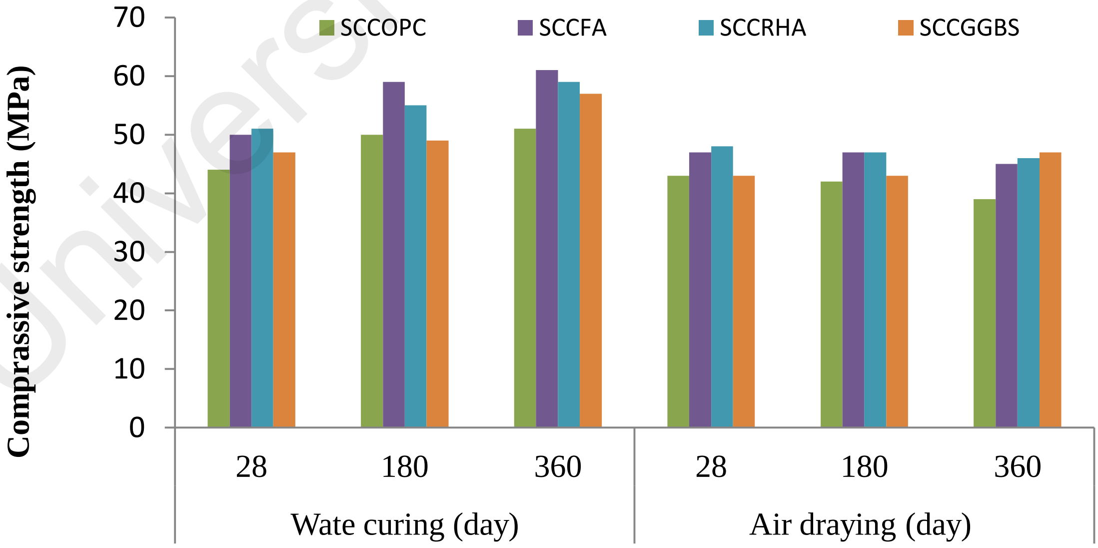

Figure 4.23: Comparison between water curing strength and air drying strength SCC

4.10.2 Flexural and splitting tensile

4.10.2.1 Effect of the curing ages on flexural and splitting strength

The effect of curing ages for 28 and 180 days on flexural and tensile splitting strength of self compacting concrete containing FA, RHA, and GGBS are presented in Table 4.22. The flexural strength in Figure 4.24 demonstrates that the flexural strength increases in parallel with the increasing of the curing ages.

The relationship between the 28 and 180 days splitting tensile and the curing ages of the self compacting concrete containing FA, RHA, and GGBS it indicates that when the curing ages increases, the splitting strength also increases. The British as well as ASTM standards require that all the flexural and

splitting strength test specimens be tested in a wet or moist condition. This condition has the advantage of being better than a dry condition which includes widely varying degrees of dryness (Neville, 1995)

Figure 4.24 demonstrates that FA and RHA have high flexural strength than OPC and GGBS. This is because of the higher content of silica in the compound. According to Haque (1984), the rate of strength variation also depends on the consistency and presence of different chemical admixtures.

Table 4.22 compares the mixes containing SCM (FA, RHA and GGBS) with normal SCC concrete. As can be seen, the improvement of flexural and splitting strength at 180 days relative of 28 days is also due to the influence of a very high ratio of pozzolanic materials and silica.

Table 4.22: Flexural strength and splitting tensile strength of SCC

Mix. No	Flexural strength (MPa)		Splitting tensile (MPa)		Rate of Flexural strength 180d / 28d	Rate of splitting tensile 180d / 28d
	28 d	180 d	28 d	180 d		
SCCOPC	3.8	4.6	3.03	3.39	1.21	1.12
SCCFA15	4.2	5.2	3.86	3.92	1.23	1.02
SCCRH10	4.8	5.4	3.44	3.69	1.13	1.07
SCCGGBS5	4.2	4.6	2.94	3.26	1.09	1.11

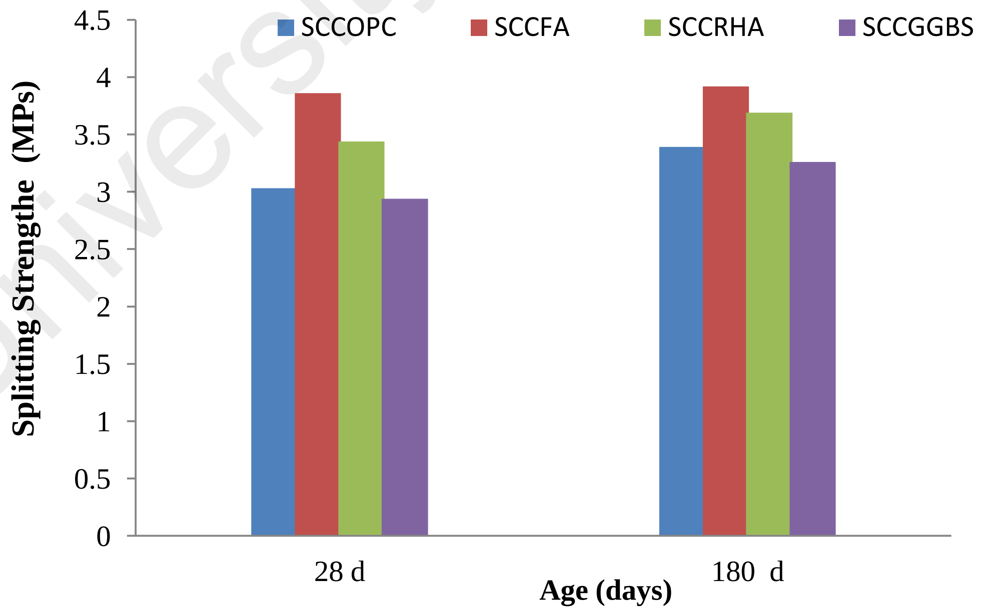

Figure 4.24: Relationship between curing ages and flexural strength of SCC

4.10.2.2 Relationship between the modulus of rupture and compressive strength

Compressive strength and flexural strength details are illustrated as shown in Table 4.23 below. The modulus of rupture or flexural strength of normal concrete is given by equation 4.6 (Nawy, 1997)

$$f r = 0.60\sqrt{f c} \qquad 4.6$$

For high-strength concrete, the modulus of rupture is (ACI, 363,1992)

$$fr = 0.94\sqrt{f c} \qquad 4.7$$

The experimental data from the SCC mixes was used to derive the relationship that is similar to Equations 4.6 and 4.7 for SCC. Figure 4.25 and table 4.23 shows the connection between the modulus of ruptures f_r and f_{cu} *at* 28 and 180 days for SCC mixes containing FA, RHA and GGBS with a correlation coefficient of 0.80 and 0.96 respectively.

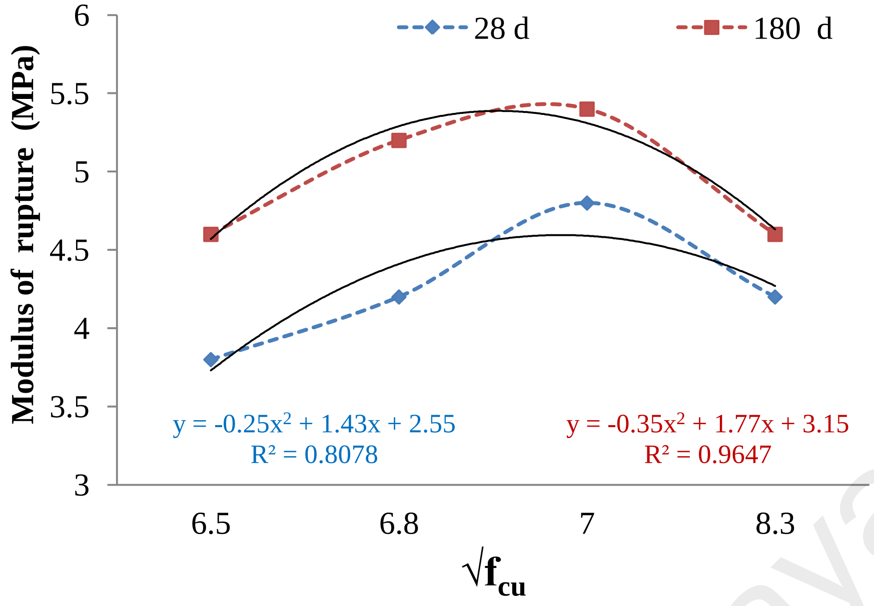

Figure 4.25: Relationship between modulus of rupture and compressive strength $\sqrt{fc}$

From equations 4.8 to 4.10 below and Figure 4.26, it can be concluded that the modulus of rupture of SCC containing SCM are comparable with concrete of normal and high strength. Equations 4.7 and 4.6 is used to calculate the modulus of rupture (ACI, 363,1992; Nawy, 1997), and it is the proportion with the desired strength of this study (40).

The resulting equation relating the modulus of rupture (*fr*) and compressive strength at 28 and 180 days ($\sqrt{fc}$) for SCC with various SCM such as FA, RHA and GGBS are given as according the Figure 4.26.

$$fr_{SCCFA} = 0.97\sqrt{fc} \quad 4.8$$

$$fr_{SCCRHA} = 0.97\sqrt{fc} \quad 4.9$$

$$fr_{SCCGGBS} = 0.46\sqrt{fc} \quad 4.10$$

Table 4.23: Relationship between compressive strength and modulus of rupture

Mix. No	W/b %	Modulus of rupture (MPa)			$\sqrt{fc}$	$\sqrt{fc}$	$\sqrt{fc}$
		28 d	90 d	180 d	28 d	90 d	180 d
SCCOPC	0.53	3.8	4.1	4.6	6.6	7.1	7.2
SCCFA	0.53	4.2	4.7	5.2	6.7	7.6	8.3
SCCRH	0.53	4.8	5.1	5.4	6.4	6.6	6.9
SCCGGBS	0.53	4.1	4	4.6	6.3	6.5	6.7

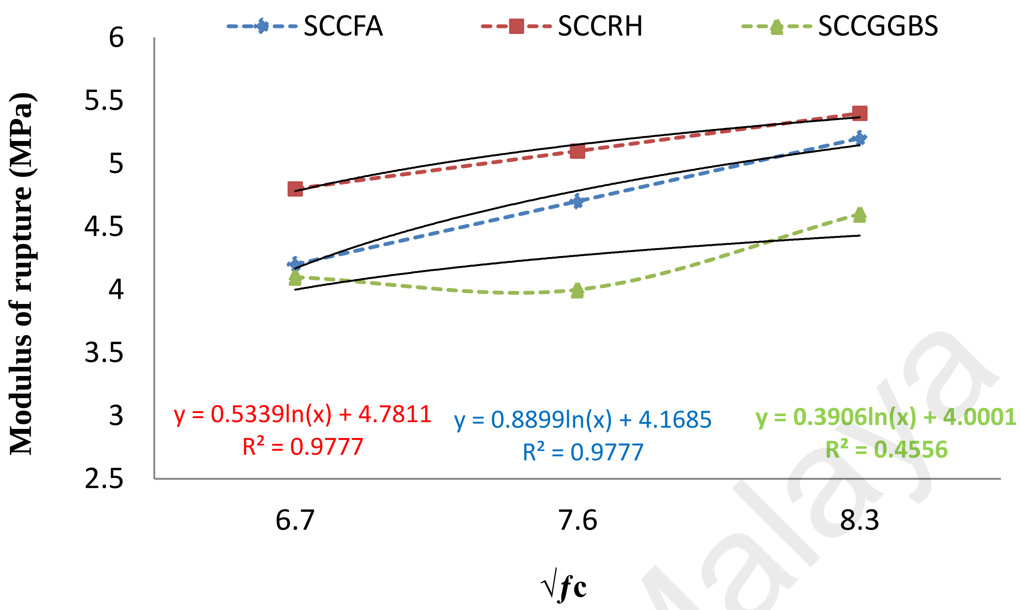

Figure 4.26: Relationship between modulus of rupture and compressive strength

4.10.2.3 Relationship between the flexural and splitting tensile strength.

The effect of adding the materials FA, RHA and GGBS on the 28 and 180 days flexural strength and splitting strength of self-compacting concrete are shown in Table 4.22 Figure 4.27. This figure indicates all results that are related with the requirement of normal SCC. Tensile strengths are based on the indirect splitting test on cylinders.

For SCC, the tensile strengths and ratio of tensile and compressive strengths are in the same order of magnitude as the conventional vibrated concrete (Ouchy, 2003).

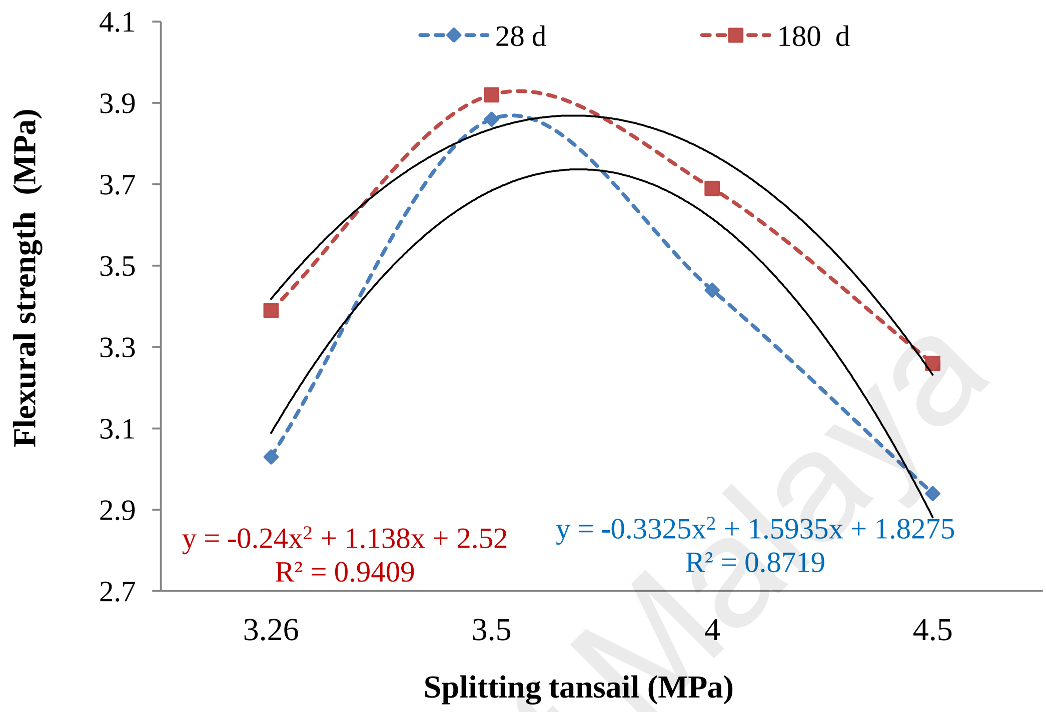

Figure 4.27: Relationship between the splitting tensile and flexural strength of SCC

Comparison of experimental data showed that the results obtained are concordance and thus bring the possibility of SCM to give strength to concrete.

4.10.2.4 Relationship between splitting tensile and compressive strength of SCC

Literature has shown several relationships between splitting tensile strength and the compressive strength of concrete. Most of these equations are applicable to certain strength ranges and types of concrete. Splitting tensile strength (f_{sp}) for normal weight concrete is related to the compressive strength, as indicated in Equation 4.8 (ACI Committee 363, 1992).

$$f_{sp} = 0.59\sqrt{fc} \qquad 4.11$$

The following relationship was suggested for concrete with compressive strength in the range of 21 to 83 MPa (Carrasquillo, et al, 1981).

$$f_{sp} = 0.54\ \sqrt{f_c} \qquad 4.12$$

For moisture-cured concretes with compressive strength in the range of 85 to 130 MPa, the following equation was suggested (Burg, 1992).

$$f_{sp} = 0.61\ \sqrt{f_c} \qquad 4.13$$

Rapheal (1984), suggested the following relationship for concretes with a compressive strength below 57 MPa (Rapheal, 1984):

$$fsp = 0.313\sqrt{fc} \qquad 4.14$$

The following relationship was also suggested for concrete with a compressive strength of less than 84 MPa (Ahmad, 1985).

$$f_{sp} = 0.462\ f_c^{\ 0.55} \qquad 4.15$$

Experimental data for splitting tensile strength and compressive strength from SCC containing FA, RHA, and GGBS at 28 and 180 days gave relationship similar to Equations 4.12 to 4.13. Figure 4.27 show a linear relationship between f_{sp} and f_c, where *FA* = 0.578, RHA = 0.573, and GGBS = 0.4808.

Equations 4.16 to 4.20 are compared with equations 4.12 to 4.15. The comparisons indicate that the splitting tensile strength for self compacting concrete containing supplementary cement material grade 40 at 28 and 180 days is very high than the normal SCC concrete. The equations are given as:

$fsp = 0.578\sqrt{fc}$ for- SCCFA *180 Day* 4.16

$f_{sp} = 0.573\sqrt{fc}$ for- *SCCRHA- 180 Day* 4.17

$f_{sp} = 0.4808\sqrt{fc}$ for – *SCCGGBS-180 Day* 4.18

$f_{sp} = 0.461\, fc^{0.55}$ for - *SCCFA -180 Day* 4. 19

$f_{sp} = 0.464\, fc^{0.55}$ for – *SCCRHA-180 Day* 4.17

$f_{sp} = 0.387\, fc^{0.55}$ for- *SCCGGBS -180 Day* 4.20

And f_{sp} and ($fc^{.55}$) (correlation coefficient FA = 0.461, correlation coefficient RHA = 0.464 and correlation coefficient GGBS = 0.387). The equations are related to splitting tensile strength (*fsp)* and ($fc,^{.55)}$ compressive strength for 28 to 180 days.

Table 4.24 and Figures 4.28 and 4.29 explain the relationship between splitting tensile strength versus $\sqrt{f_c}$ and $f_c^{.55}$

Table 4.24: Relationship between splitting tensile strength versus $\sqrt{fc}$, $f_c^{0.55}$

Mix. No	Splitting tensile (MPa)			$\sqrt{fc}$ 28 d	$\sqrt{fc}$ 90d	$\sqrt{fc}$ 180 d	$f_c^{0.55}$ 28d	$f_c^{0.55}$ 90d	$f_c^{0.55}$ 180d
	28 d	90d	180 d						
SCCFA15	4	4.3	4.7	7	7.6	7.7	8.5	9.4	10.26
SCCRH10	3.5	3.6	4	6.4	6.6	6.8	7.6	8.0	8.3
SCCGGBS5	2.94	2.98	3.26	6.4	6.5	6.5	7.7	7.9	8.1

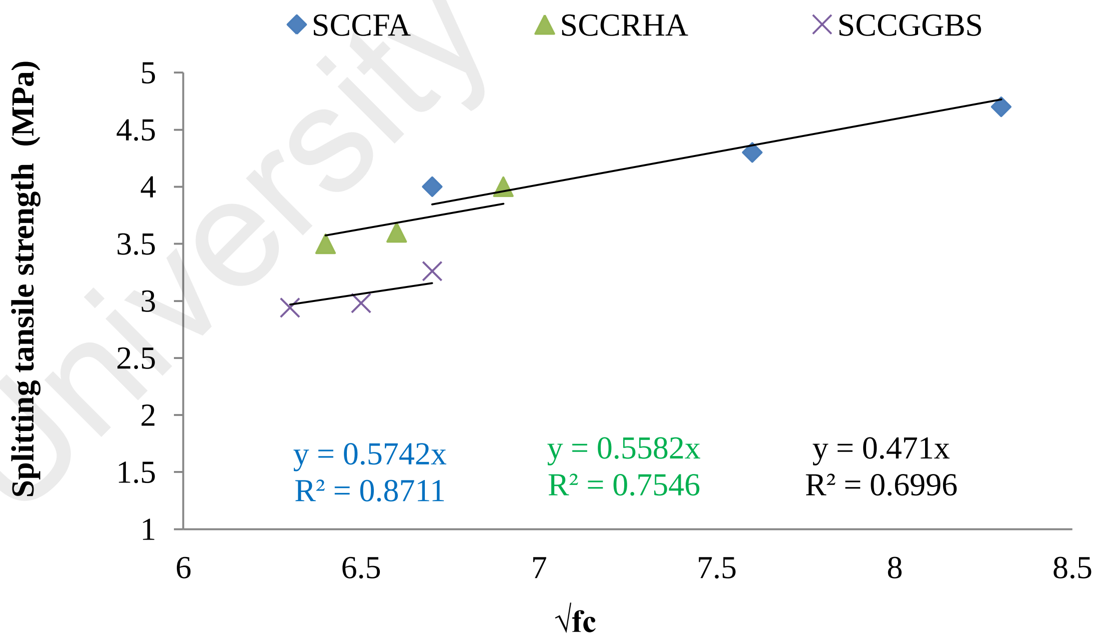

Figure 4.28: Splitting tensile strength versus $\sqrt{fc}$ at deferent ages (28, 90. 180) days

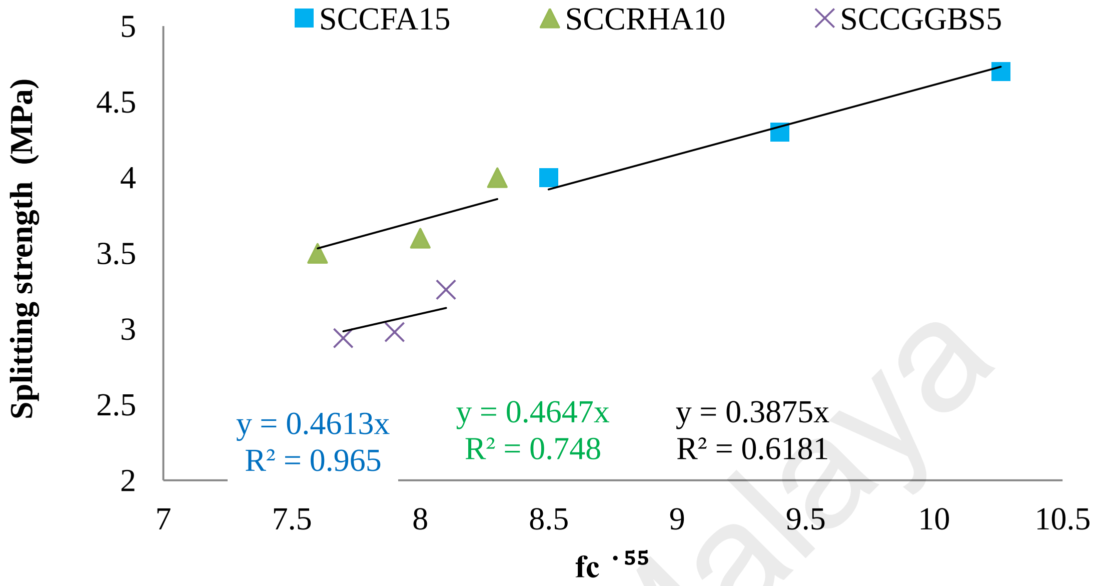

Figure 4.29: Splitting tensile strength versus $f_c^{0.55}$

4.10.3 Modulus of elasticity

4.10.3.1 Effect of curing ages on modulus of elasticity

In this study, the use of SCM show the development of mechanical properties of concrete with the continuing interaction between the components of the mixture and that leads to improvement of the compressive strength at different curing ages of 7, 28, 90, 180, and 360 days, as shown in Figure 4.30 and Table 4.25. This explains the improvement of modulus elasticity of concrete containing SCM with age. As compared to SCCOPC, the correlation coefficient indicated is high and is equal to 0.9394, 0.9639, 0.9427 and 0.9431 for SCCFA, SCCRHA, SCCGGBS and SCCOPC respectively.

Observation on the modulus of elasticity showed a significant growth for SCCOPC and SCCGGBS at earlier ages. As for the FA and RHA, high rate of pozzolanic cause both materials to have slow or late reconstruction and it is shown in Table 4.25.

In Dehn et al. (2000), the elastic modulus for SCC containing SCM with FA and RHA are higher than that of traditional concrete, indicating that SCC is rigid than traditional concrete. Thus the development of modulus of elasticity can be observed in this study.

Table 4.25: Modulus of elasticity of SCC containing SCM

Mix. No	W/b	Modulus of elasticity (GPa)			Ratio Modulus of elasticity 180d / 28d	Ratio Modulus of elasticity 660d / 28d
		28 d	180 d	660d		
SCCOPC	0.53	30	31	33	1.03	1.10
SCCFA15	0.53	30	32	38	1.06	1.26
SCCRH10	0.53	29	31	34	1.07	1.17
SCCGGBS5	0.53	29.3	30	31	1.04	1.04

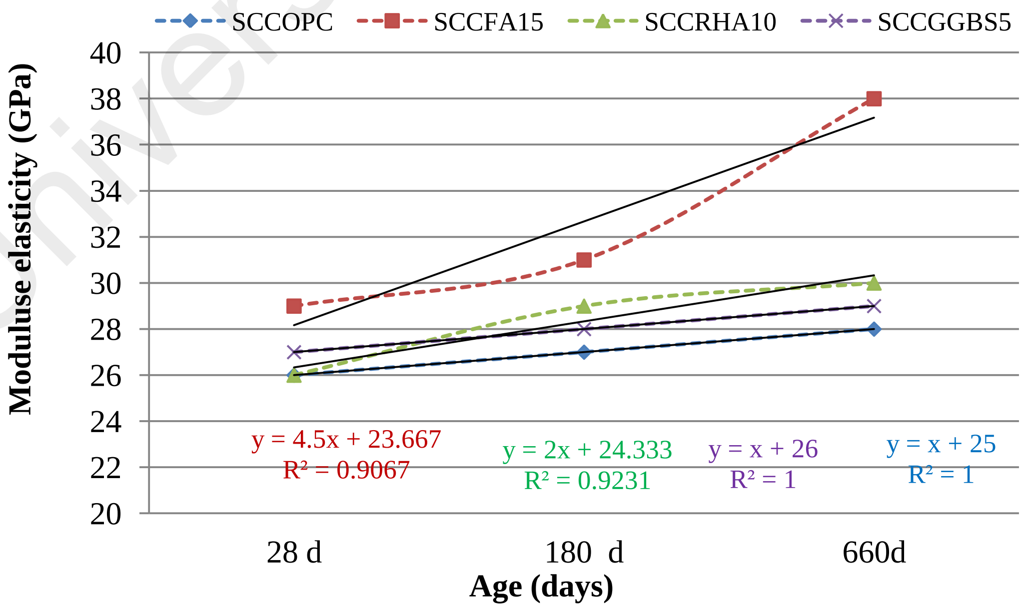

Figure 4.30: Relationship between the modulus elasticity and curing ages

4.10.3.2 Modulus of elasticity, density and compressive strength of SCC concrete

Observations on the obtained equations showed that the values of factors are concentrated but there are variations in the value of compressive strength according to the type of additive materials. We acknowledge that FA containing materials have a higher strength compared to other additives (RHA and GGBS) that cause the modulus of elasticity to increase. The results indicate that generally as the concrete strength increases, so the modulus elasticity, although the rate of increase is less compared to the rate of increase strength (e. a. Mahmud, 2009).

The relationship details between modulus elasticity, compressive strength and air dry-density of SCC are presented in the Table 4.26.

Table 4.26: Relationship between modulus elasticity and $\rho^{1.5}\sqrt{fc}$ of SCC containing SCM

Mix. No	ρ (Kg/m^3)	Compressive strength (MPa)		$\rho^{1.5} * \sqrt{fc}$		Modulus of elasticity (GPa)	
		28 d	180d	28 d	180d	28 d	180 d
SCCOPC	2350	44	50	756677	802536	30	31
SCCFA15	2390	46	69	823025	905328	30	32
SCCRHA10	2355	41	47	722282	779606	29	31.5
SCCGGBS5	2362	40	45	733747	745212	29.3	30

The modulus of elasticity of concrete is a function of the relative amount of paste and aggregate along with the modulus of each constituent (ACI Committee 213-87). Concretes vary widely in their composition, and as such, their modulus of elasticity may differ. Researchers have shown that the modulus of elasticity for normal weight concrete is related to its density and cylinder compressive strength as in equation 4.21 (ACI Committee 318-95).

The equation is valid for concrete of density in the range of 1440 kg/m³ to 2480 kg/m³, and the unit for the modulus of elasticity is GPa.

$$E = 0.000043\ \rho^{1.5} \sqrt{fc} \qquad 4.21$$

For lightweight concrete, the modulus of elasticity is lower than normal weight concrete. Although equation 4.22 covers density ranges of lightweight concrete, it may not be directly applicable to palm oil clinker POC concrete and other lightweight concretes. This is because, the properties of the aggregate also affect the modulus of elasticity of concrete, which is given as (Hassan, 2008).

$$E = 0\ .00001\ \rho^{1.5} \sqrt{fc} \qquad 4.22$$

A moderate low modulus of elasticity for POC concrete is shown in Equation 4-3) and it was compared to equation (4-4) of normal concrete.

This study indicates an equitable convergent with value of modulus elasticity for SCC containing OPC, FA, RHA, and GGBS compared with normal concrete and lightweight concrete at Equation 4.22 and 4.23 and the four equations below (4.24) to (4.27). This can be explained by the addition of SCM materials to SCC concrete with fine particles to fill the voids efficiently. Thus, the hardness obtained is as desired. Furthermore, larger elastic modulus Figure 4.30 and Eq (4.23) to (4.26) and hard concrete contribute to high modulus of elasticity when proportion of 55/45 was used.

Domone reported an approximate 40% lower stiffness of SCC mixes in comparison to normally vibrated concrete mixes at cube strengths of 20– 30 MPa, and approximately 5% lower than normally vibrated concrete at cube compressive strengths of 80–100 MPa. This behavior was attributed to the relatively lower coarse aggregate quantities in SCC in comparison to normally vibrated concrete (Domone, 2007).

In this study the size of coarse aggregate used relatively highest of the normal size which used with normal SCC concrete and that leads to improvement modulus elasticity approximately 5% according to the normal SCC shown in Table 4.25.

$$E\ sccopc = 0\ .000040\rho^{1.5}\sqrt{fc} \tag{4.23}$$

$$E_{SCCFA} = 0\ .000035\rho^{1.5}\sqrt{fc} \tag{4.24}$$

$$E_{SCCRHA} = 0\ .000040\ \rho^{1.5}\sqrt{fc} \tag{4.25}$$

$$E_{SCCGGBS} = 0.000040\,\rho^{1.5}\sqrt{fc} \qquad 4.26$$

Equation (4.25) indicates a fairly low modulus of elasticity for SCCFA concrete compared to equation (4.24), normal SCCOPC concrete because the ratio of fine materials is higher in other types of concrete containing SCM, therefore reduced the elastic modulus factors.

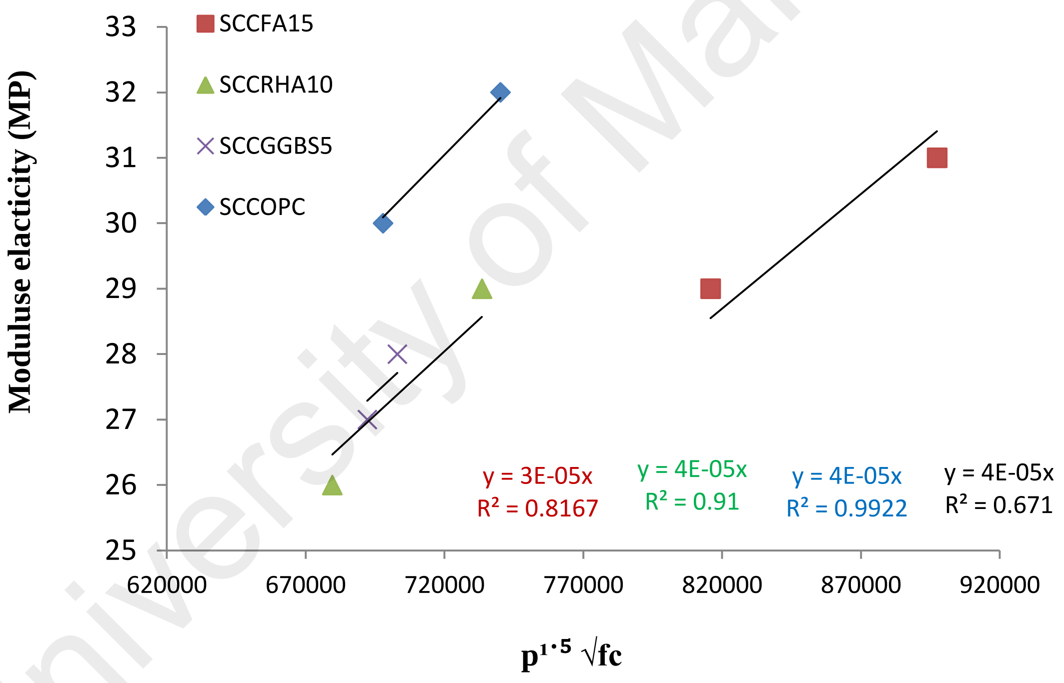

Figure 4.31: Modulus of elasticity versus $\rho^{1.5}\sqrt{fc}$

4.10.3.3 Development of Poisson, ratio in SCC with various SCM

Experimental data for Poisson ratio of SCC containing FA, RHA, and GGBS at 28 and 180 days and is presented in Table 4.27 and Figure 4.32. This figure indicates all results with the standard limits of concrete at a maximum of 0.2. The value of Poisson ratio for concrete in constant depends on the properties of the aggregate used for Poisson ratio of concrete. It lies generally in the range of 0.15 to 0.22 when determined from strain measurement under the compressive load of the value of Poisson ratio under tensile load and it appears to be the same as a compression (Neville, 1995).

The generally accepted range of the Poisson's ratio of SCCOPC is between 0.15 and 0.25, while it is generally assumed to be 0.2 for analysis. Test data from this project suggest that it is reasonable to use 0.2 as Poisson's ratio for HSC up to compressive strength of 124 MPa (Neville, 1995).

Table 4.27: Curing ages and Poissons ratio SCC

Mix-No	W/b	Poisson, ratio	
		28 d	180 d
SCCOPC	0.55	0.15	0.16
SCCFA15	0.55	0.17	0.19
SCCRHA10	0.55	0.16	0.17
SCCGGBS5	0.55	0.18	0.19

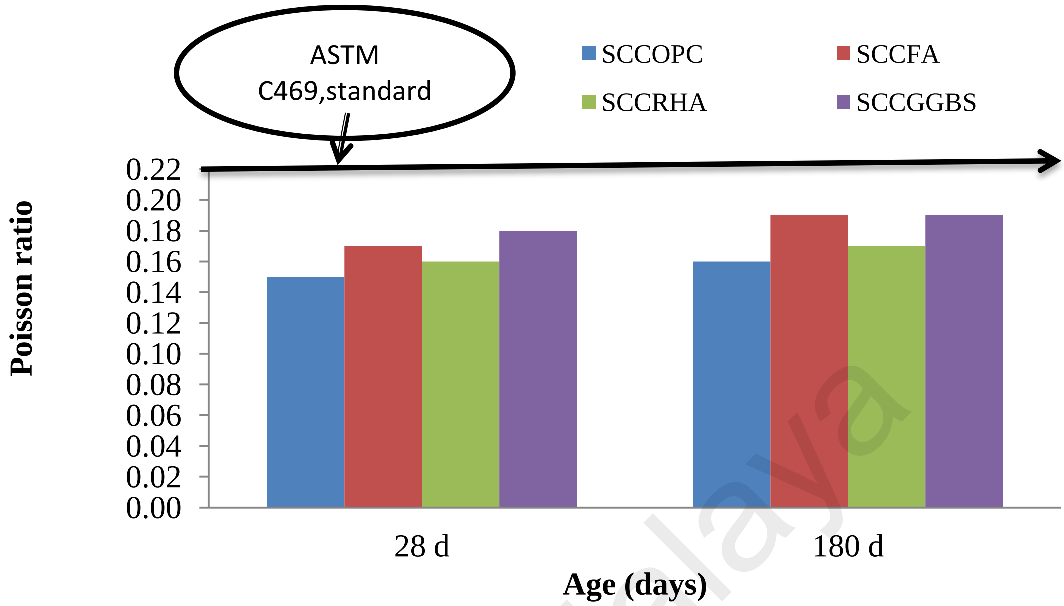

Figure 4.32: Relationship between curing age and poisson ratio of SCC

The relationship between Poisson ratio and compressive strength is depicted in Figure 4.33. As depicted, all SCM mixes show growth in Poisson ratio. However, the ratio is still low as the one for normal concrete, which according to ASTM C-469, the standard ratio is between 0.15 and 0.22.

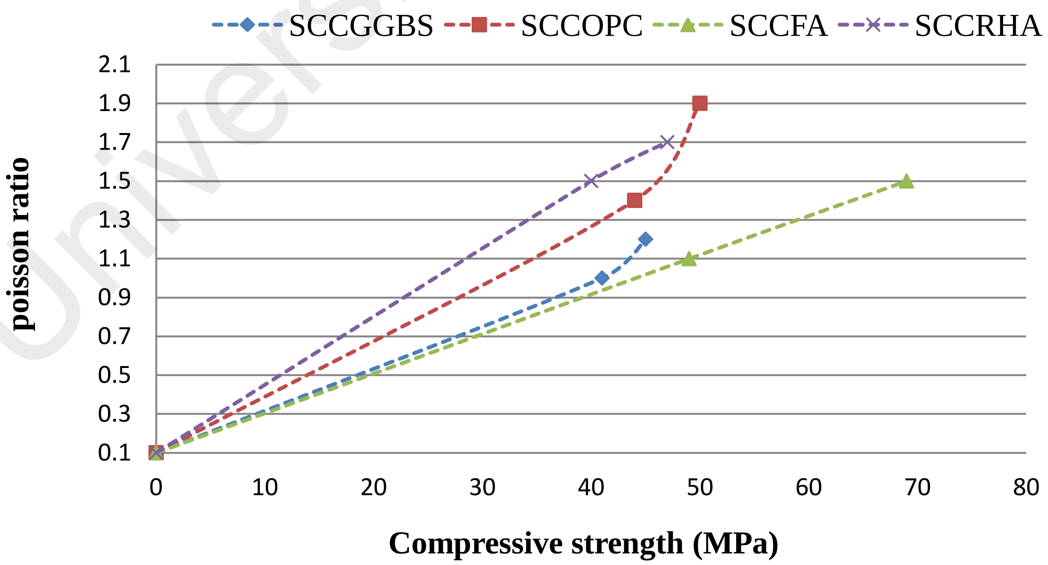

Figure 4.33: Relationship between the compressive strength and Poisson ratio of SCC

4.10.4 The density and strength of SCC

Figure 4.28 and Table 4.29 shows the relationship between SSD, Air Dry, Oven Dry and the curing ages, and this shows that when we increase the curing ages, the SSD density was increased. This is because the whole void is been filled by the SCM in the SCC. Thus, it leads to the increment of the density (Table 4.29and Figure 4.35). Despite the varied proportions of SCC from those of traditional concrete, it is worth noting that the density values of SCC are similar to those of traditional vibrated concrete, indicating a good compaction of SCC (Khatib, 2008).

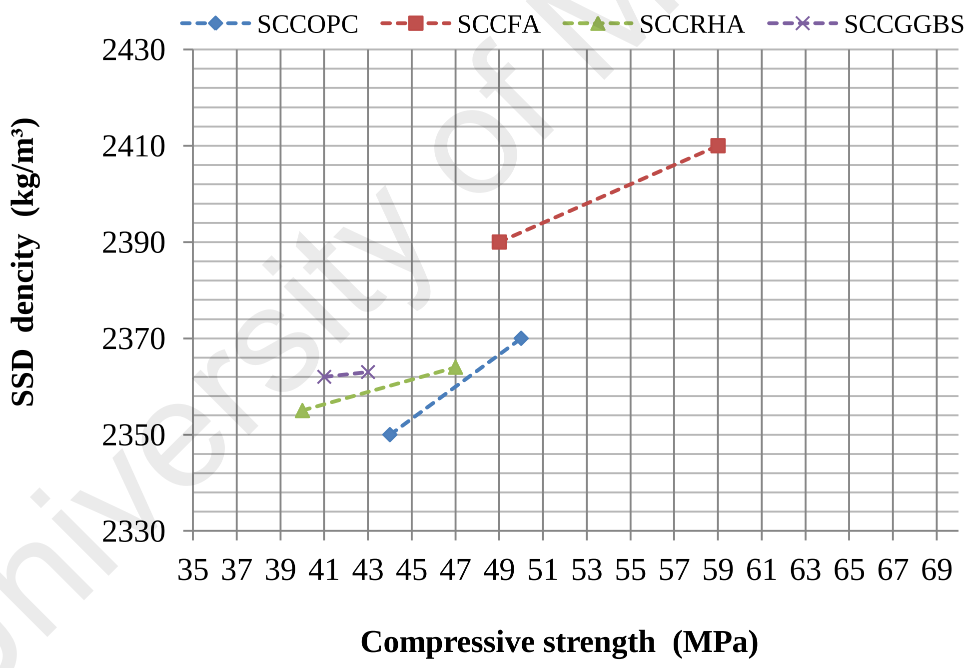

Figure 4.34: Relationship between SSD density and compressive strength of SCC

Table 4.28: Relationship between SSD and strength of SCC

Mix-No	SSD-density (Kg/m^3)		Compressive strength (MPa)	
	28 d	180 d	28 d	180 d
SCCOPC	2350	2370	44	50
SCCFA	2390	2410	49	59
SCCRHA	2355	2364	40	47
SCCGGBS	2362	2363	41	43

4.11 Time dependent property of SCC containing SCM

The effect of using various SCC mixtures on drying shrinkage and expansion is illustrated in Table 4.30. These explain the drying shrinkage in the early ages for mixes containing the SCM (FA, RHA, GGBS) compared with normal SCC is because of the increasing ratio of fine materials that filled most of the void and cause the concrete to hardness and reduce the permeability of water. The expansion exhibited different behavior because the swelling of the concrete is depending on the particle size and fineness degree of SCM. This directs to the conclusion that the closure of almost the entire space is efficient by shrinkage in the concrete.

Findings of this study showed that binder ratio of cement + SCM was the higher compared with normal concrete. It is generally agreed that shrinkage increases with the increase of the cement content because this resulted in a large volume of hydrated cement paste which is liable to shrink (Neville, 1995). Note that in this study, negative strains values represent contraction shrinkage and positive strain values represent an expansion. Over time, the expansion change from positive to negative values in parallel with the hydration of the cement and completeness of their interaction with SCM.

Table 4.29: Drying shrinkage and expansion of SCC

Mix	Drying shrinkage (µm)					Expansion (µm)				
	7 d	28 d	90 d	180 d	360 d	7 d	28 d	90 d	180 d	360 d
SCCOPC	-128	-153	-202	-250	-262	38	118	130	145	173
SCCFA 15	-65	-110	-161	-198	-233	35	102	115	135	161
SCCRHA10	-71	-123	-181	-215	-245	31	72	87	109	128
SCCGGBS5	-117	-140	-192	-223	-256	36	115	121	140	169

4.11.1 Drying Shrinkage of SCC

The effect of using various SCM with SCC on drying and wet shrinkage and its comparison with normal SCC containing different SCM is presented in Figure 4.36. As can be seen, the SCM mixes have high water resistibility because most of the voids are being closed or filled.

The drying shrinkage and curing shrinkage is still high but within normal concrete limits. Because the powder ratio at the mixes is very high, the voids are much less. The expansion of the concrete cause the voids closure efficiently.

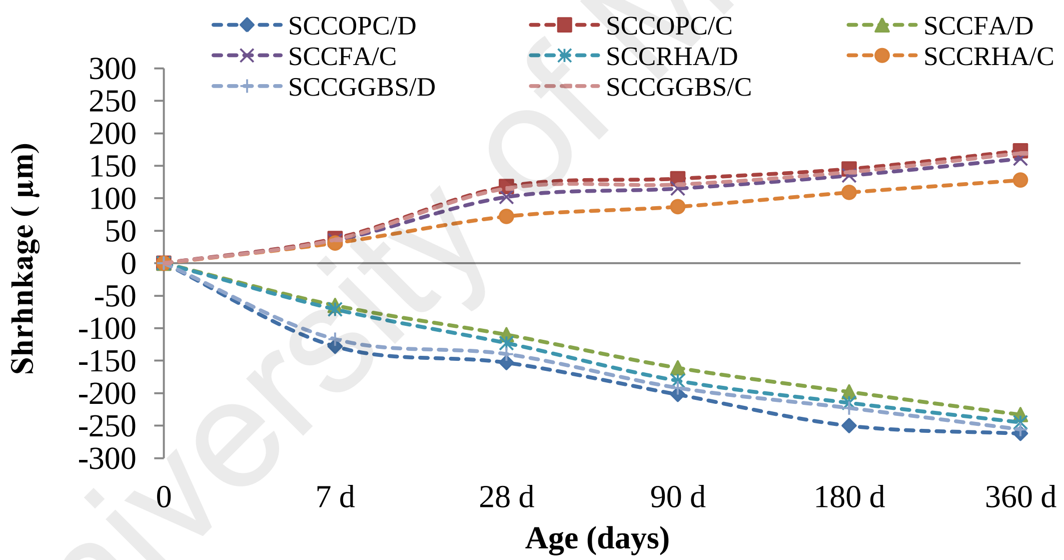

Figure 4.35: Results of drying shrinkage and expansion of SCC

4.11.1.1 Effects of SCM on drying shrinkage

The result shows that the SCC concrete containing SCM of grade 40 explain normal behaviour in the drying shrinkage test compared to normal concrete.

But when compared to the SCCOPC specimen, concrete with FA and RHA is shows to be simple and less than GGBS because of the larger fineness of the two compared to GGBS. Therefore, they filled the void faster than GGBS.

The ratio of pozzolanic materials is higher than for the GGBS; one of the reasons is the use of SCC is to improve the durability of concrete structures. The drying shrinkage tends to decrease in SCC since a very small amount of free water is available in the system. Also, SCC has minimum voids on concrete surface that are largely responsible for drying shrinkage(Cusson, 2008). Figure 4.38 shows that the mixes which containing SCM including SCCOPC is closed with others mixes because higher aggregates used (55%) cause the binder ratio to increase and consequently increases the force bonds between the content of materials content.

Comparison of this study results with other research using 10% RHA results are shown in Table 4.31.

Table 4.31: Comparison between drying shrinkage and expansion concrete

Author of paper	Type of additive	Ratio of additive %	Shrinkage strain (µm)		Remark
			Air Drying between (28 to360)d	(Expansion) between (28 to360)d	
Aiad,2012 SCCRHA10 grade 40	RHA	10	71-245	72-128	*w/b, 0.53 *cement 406kg
Mahmud, (JACT) NCRH10 grade 40	RHA	20	123-205	82-177	*w/b,0.38 *cement 450kg
Aiad,2012 SCCFA15, grade 40	FA	15%	65-233	35-161	*w/b, 0.53 406 Kg
Mahmud, PHD theses ,1985,NCFA, grade 40	FA	50	319-452	126-230	*w/b,0.42

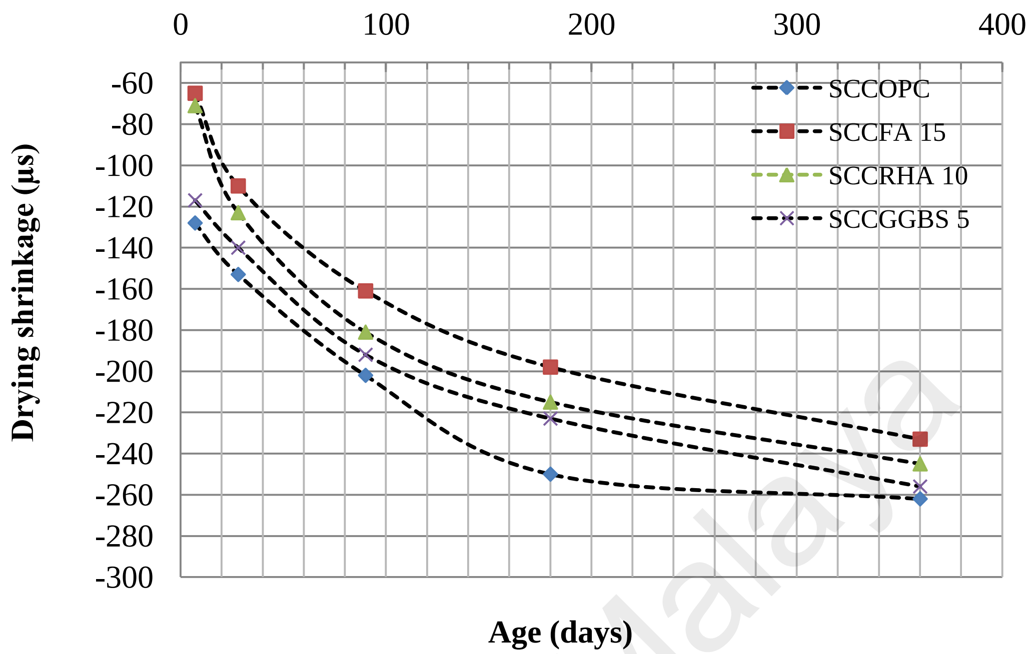

Figure 4.36: Relationship between the drying shrinkage and curing ages

4.11.2 Effect of SCM on expansion of SCC

The experimental consequences reveal that the concrete containing SCM of 40 MPa shows normal behaviour for swelling in the volume of the concrete sample. According to the Physical specifications for SCM degree of fineness and silica ratio influence the expansion of SCC. Results also show that fineness degree of FA is higher than GGBS and silica ratio in RHA is higher than FA and GGBS.

The results lead to less swelling in the FA and RHA mixes than for the GGBS. The extent of expansion increases with the quantity of moisture in the concrete mix. Johansen et al. (2002) has reported that the cracking risk may increase by the reduction in w/b ratio or increment of paste volume. Thus, addition of SCM to SCC must be controlled.

In Figure 4.38, first, all the mixes were controlled regarding to moisture for all the materials used. Secondly, the expansion of the FA and GGBS is higher compared to concrete containing RHA at the final ages because the RHA contains higher proportion of pozzolanic material than the FA contain 15%, RHA 10% and GGBS 5% according to the chemical composition of SCM.

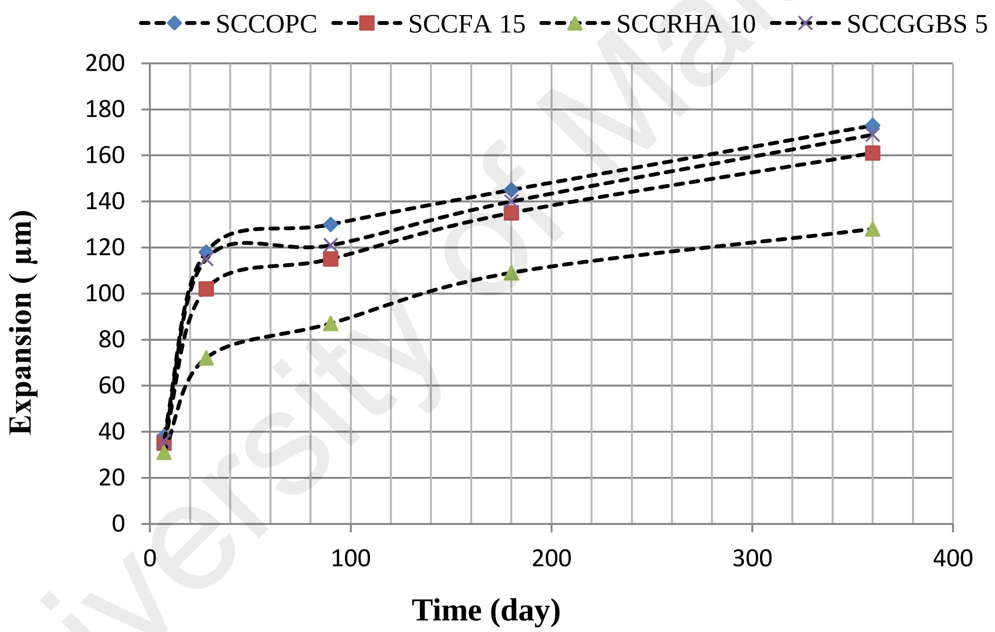

Figure 4.37 : Relationship between the expansion and curing ages

4.12 Cost analysis on normal concrete and SCC

Cost analysis of the materials used has been analyzed as per purchased price from the market on May 2012. The selected mixes for calculation and analysis were those which satisfy the requirement properties of freshly mixed concrete such as SCCFA, SCC RHA and SCCGGBS. Keeping these criteria, the selected mixes were NC among the control concrete mixes, and FA15, RHA10, and GGBS5 among the mixes

Containing fly ash (FA), rice husk ash (RHA), and ground granulated blast-furnace slag (GGBS). Detailed calculations are summarized in Table 4.33. It is clear that the cost of ingredients of specific SCC containing FA, RHA, and GGBS are higher than the normal concrete NC by 8%, 10% and 4% respectively.

But there are extra costs included with normal concrete that can increase the cost per cubic meter of concrete such as compaction, which we can be avoided by using self-compacting concrete, and this is a contribution that needs to be added to this type of concrete. Finally the cost of SCC reduced by ratio of 25% for wages relating to the work of casting and mechanical compaction as a result, the real cost of concrete reduced in the 9% for all SCC mixes containing FA, RHA and GGBS compared with normal concrete

Table 4.38 illustrates the comparison of cost for NC and cost for SCC. The table shows that the difference for FA, RHA and GGBS of SCC are 10%, 8% and 4% on successfully and after the addition of the wages of the labor force of 25% becomes 32% rate.

Table 4.32: Mix proportion per m³

Mix .No	W/b %	Cement (kg)	F.A (kg)	C.A (kg)	Water (kg)	S.P %	Admixtures (FA,RHA,GGBS)
SCCOPC	0.53	406	895	732	215	2	0
SCCFA 15	0.53	349	895	732	201	2	57
SCCRHA 10	0.53	369	895	732	201	2	38
SCCGGBS 5	0.53	388	895	732	201	2	18

Table 4.33: Cost analysis to produce content and SCC

Material	Rate per (RM)	Control Concrete NC		Self compacting concrete SCC	
		Quantity (kg)	Amount (RM)	Quantity (kg)	Amount (RM)
Cement	0.40	406	163	380	152
Coarse Aggregate	0.25	732	183	732	183
Sand	0.20	895	179	895	179
Superplasticizer (Sika Viscocrete 1600) (Lit)	40	2	80	2	80
(RHA)	1.1	_	0	57	63
(FA)	2	_	0	38	76
(GGBS)	2	_	0	18	36
Total			605		
	Percent reduction in cost RHA = 8% 657				
	Percent reduction in cost FA = 10% 670				
	Percent reduction in cost GGBS= 4% 630				

CHAPTER 5: DURABILITY OF HARDENED SCC CONCRETE

5.1 Background

One major challenge facing the civil engineering community is to execute projects in harmony with nature by using the concept of sustainable development involving the use of high performance and environmental friendly materials produced at a reasonable cost in the context of concrete, which is the predominant building material. It is necessary to identify less expensive cement substitutes.

In recent years, many researchers have established the use of supplementary cement materials such as fly ash, blast furnace slag, silica fume, metakaolin, and rice husk ash that can improve the properties in fresh and hardened states of the concrete, as well as curbing the rise in construction costs (Mehta, 1999).

In this study, enhancement of the durability and workability properties of normal self-compacting concrete (SCC) along with the concrete containing rice husk ash (RHA), fly ash (FA), and ground granulated blast furnace slag **(**GGBS) were studied. To establish a suitable proportion, 10%, 15% and 5% of cement was replaced by RHA, FA, and GGBS, respectively. The durability properties were studied through the measurement of permeable voids, water absorption, porosity, and ISAT by measuring the concrete penetration and conducting the rapid chloride permeability test (RCPT). The SCC has higher permeable voids and water absorption compared with vibrated normal concrete of same strength grade. Additionally, it also has improved workability in range 600 – 700 mm slump flow, durability and homogeneity by addition of plasticizer in the mixtures.

It is a usual practice to assess the water permeability characteristics when assessing the durability characteristics. Permeability can be measured by conducting a water permeability test as per standards, water absorption test or initial surface absorption test. In the present investigation, water absorption and the permeable voids were determined as per given procedure in ASTM C- 642 (ASTM, 1994). The absorption and permeable voids were determined on three 100 mm cubes. Saturated surface dry cubes were kept in air oven at 105 °C until a constant weight was attained. The ratio of the difference between the mass of saturated surface dry specimens and the mass of the oven dried specimens at 105 °C to the volume of the specimen (1000 ml) gives the permeable voids in the specimen (ACI & 1995).

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Many researchers have discussed the effect of mixtures on the durability of concrete and explained the impact of the general specifications for concrete. The transport properties and durability of concrete are affected by the permeable porosity which is related to process of deterioration caused by the concrete transport properties. For example, the corrosion in reinforcing bars known to be caused by the porous medium of concrete which permits the transport of chloride, oxygen, carbon dioxide, and moisture (Claisse, 2001).

In this study, we discussed the effect of a number of supplementary cement products like Fly Ash, Ground Granulated Blast Furnace Slag and Rice Husk Ash and showed the impact on the durability properties of self-compacting concrete, and this is shown in the following sections.

5.2Water permeability of SCC containing SCM

The permeability performance of SCC is closely related to several concrete properties. The following sections discuss the effects of porosity, water absorption and initial surface absorption on the SCC containing supplementary materials such as FA, RHA and GGBS.

5.2.1 Initial surface absorption test (ISAT)

The ISAT can be used as a measure of the durability near the surface cover of the concrete. In this test, six cubes were used and cured at 28 and 180 days. The test was conducted to determine the initial surface absorption rate of the concrete, which is the rate of water flow into the concrete matrix per unit area after being subjected to a constant water pressure for a specified period of time (BS, 1996).

The results of the ISAT of the mixtures are shown in Figures 5.1 and 5.2. The SCC with the concrete containing SCM showed lower porosity compared with SCCOPC control mix. The ISAT values decreased with increasing curing ages and compressive strength. This is because the outer zone of the concrete surface became saturated as the capillaries were filled with water, making it more difficult for water to be absorbed by the inner pores (Long, 2001). Irrespective of the age of the specimen, when compared with the control SCCOPC concrete, there is a marked reduction in the ISAT values of FA and GGBS containing pozzolanic materials at the 28 curing ages, comparing with the concrete that contained RHA.

Because of this, the particle in supplementary cementitious material FA ,GGBS and respectively has closed all the spaces in the mix faster than RHA and this process repeated in the advanced ages of the concrete.

Thus, indicating the importance of incorporating pozzolanic materials to reduce the permeability of concrete. The High-reactivity Metakaolin (HRM) which is smaller than cement particles is added to concrete with typically from 5% to 10% rate by weight of cement and consequently increase the formation of additional cementitious material due to the chemical reaction of free lime by a product of portland-cement hydration. This finally provides greater concrete performance. Table 5.1 and Figure 5.1 show the mixes containing SCM such as FA, RHA and GGBS exhibited the reducing in the value of mixes during the time of the durability increases with the increasing time.

In concrete, the water absorption rate is considered high when the surface area is larger than 0.500 mL/m^2 per second after 10 minutes while it is lower when the water absorption is smaller than 0.25 ml/m^2 per second (BS 1881: Part5, 1970). Neville (1995) also found the same trend values but after 2 hours where higher than 0.15 ml/m^2 per second and lower than 0.07 ml/m^2 per second. Results from this study are also compatible with British standard, especially for SCM-containing mixtures (40 MPa).

Table 5.1: ISAT results for SCC containing FA, RHA, GGBS at different curing ages.

Mix-No	Flow (mL/m²)						Relative ISA $\frac{28d}{180\,d}$		
	ISAT 28 d			ISAT 180 d					
	10 (Min)	30 (Min)	60 (Min)	10 (Min)	30 (Min)	60 (Min)	10 %	30 %	60 %
SCCOPC	1.250	0.625	0.357	0.650	0.492	0.339	1.92	1.27	1.05
SCCFA15	0.625	0.313	0.250	0.227	0.167	0.147	0.36	0.53	0.59
SCCRHA10	1.200	0.610	0.312	0.633	0.325	0.290	1.90	1.88	1.08
SCCGGBS5	0.625	0.250	0.147	0.417	0.192	0.134	1.50	1.30	1.10

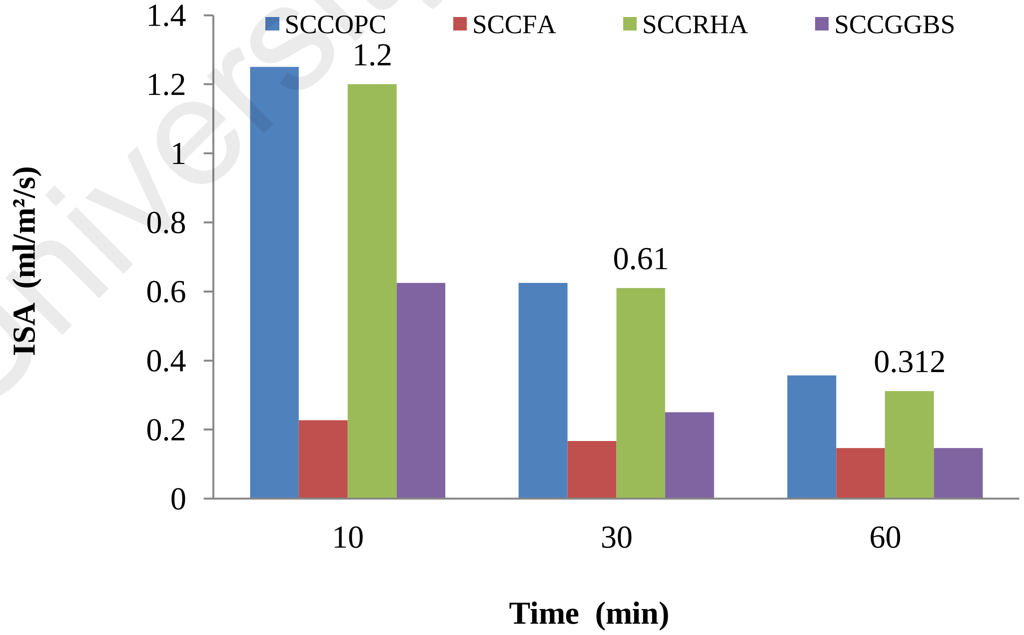

Figure 5.1: Relationship between ISA and time of SCC at 28 days

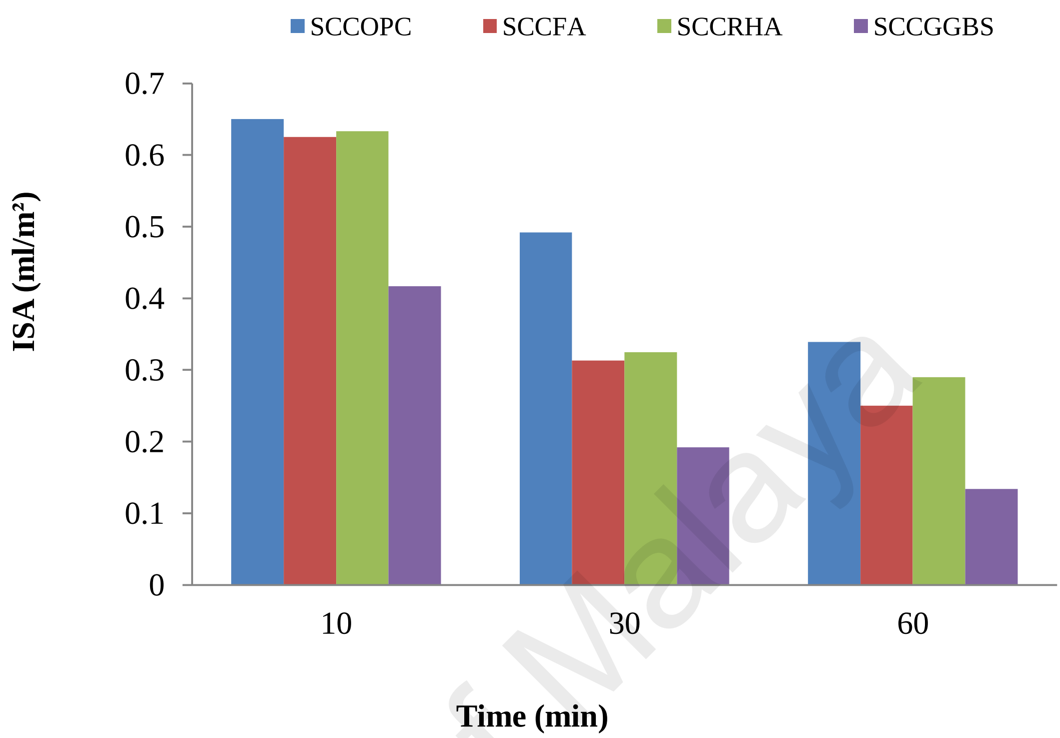

Figure 5.2: Effect curing age at180 day on I-SAT

5.2.2 Water absorption of SCC

According to BS1881 Part 122 (1983) "Testing concrete: Method for the determination of the absorption of water", three separate specimens were used to determine the absorption of SCC concrete at the ages of 28 and 180 days. The difference in mass of the specimens is the mass of the water absorbed. Water absorption can be shown through the mass, or more accurately by dividing it with the total surface area, thus giving the mass per unit area. In this study, the percentage of water absorbed by all the concrete mixtures at 28 and 180 days under one curing regime is shown in Figure 5.3.

All of the specimens have low absorption characteristics of less than 3%, and lower absorption values comparing with SCCOPC are exhibited by the cured sample (less than 2% at 180 days and beyond) based on the follow-up results obtained from practical experiments showed that the presence SCM has improved the durability for SCC compared with normal SCC, which water absorption decreases with increasing compressive strength, as shown in Figure 5.4. The pore system in SCC is more refined than in normal concrete (Attiogbe, 2002) and the pozzolanic and micro-filling effects of mineral admixtures also contribute to form a refined pore structure in SCC. The refined pore structure greatly improves the transport properties of concrete, and therefore the durability of SCC (Safiuddin, 2008)

Table 5.2: Absorption test on the SCC containing SCM

Mix.No	W/b %	Water absorption %		Compressive strength (MPa)	
		28 d	180 d	28 d	180 d
SCCOPC	0.53	2.3	2.1	44	50
SCCFA15	0.53	1.74	1.65	49	69
SCCRHA10	0.53	2.00	1.90	41	47
SCCGGBS5	0.53	2.25	2	40	43

Table 5.2 shows the comparison between the normal concrete SCCOPC and other SCM-containing mixes (FA, RHA and GGBS). It is observed that the mixes show reduction in water absorption, especially for SCCFA15 and SCCRHA10. This is because the high binder ratio and pozzolanic materials lead the concrete to hardened faster; hence close all voids and prevent water permeability to the concrete. The absorption for all concrete are below 10 percent by mass; so, any presence of water occupying the volume is to be calculated by considering the difference in specific gravity of water and of concrete (Neville, 1995).

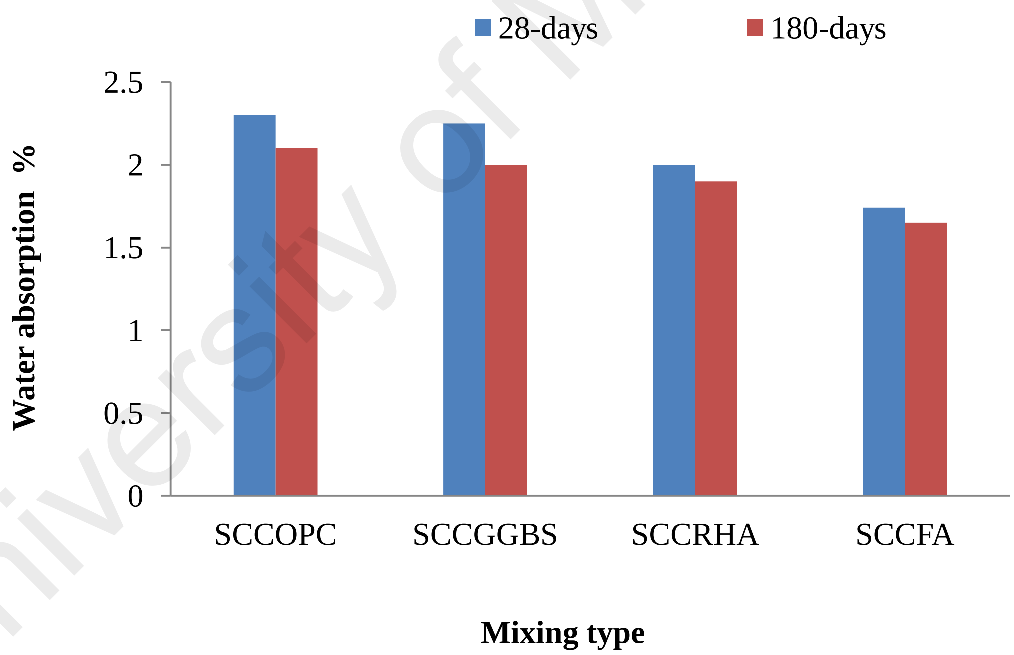

Figure 5.3: Relationship between water absorption and curing ages for various mixes

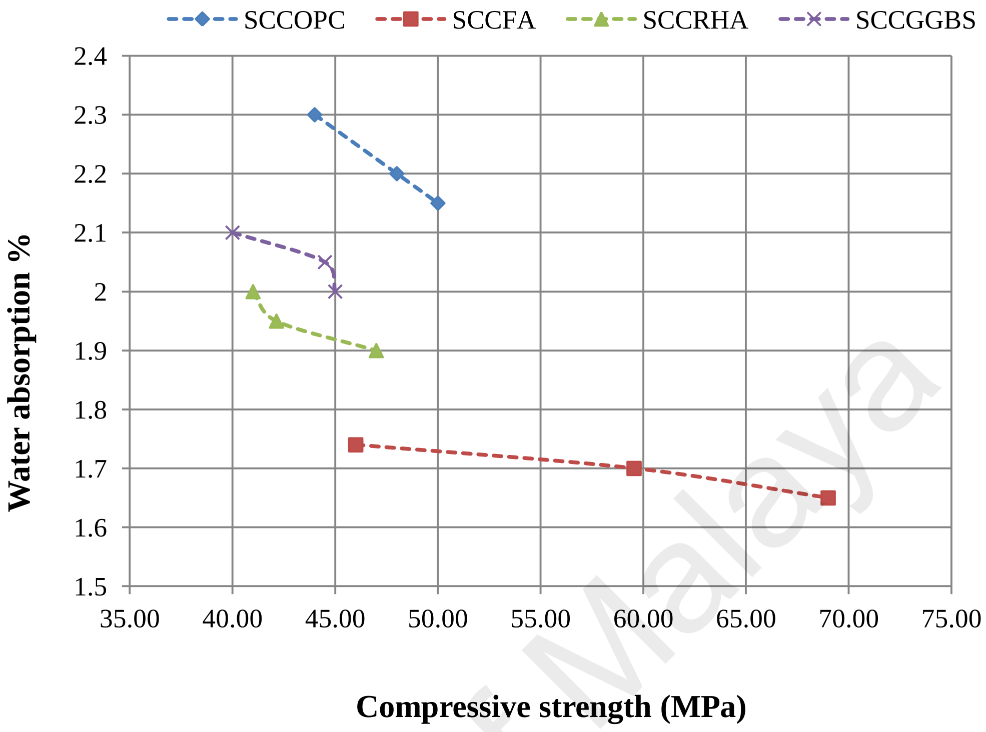

Figure 5.4: Relationship between water absorption and compressive strength

5.2. 3 Permeable Voids of SCC

Porosity of concrete is an important factor in classifying its durability. Generally, concrete with low porosity will afford better protection to any reinforcement within it than concrete with high porosity.

Porosity effect of the two testing methods cold-water and boiling-water saturation techniques using 100 x 50 mm cylinder specimens are tabulated and depicted in Table 5.3 and Figure 5.5. The results illustrated that cold-water saturation is not an effective way to be accounted for the dead-end pores and the air voids of concrete, and the ability of the cold-water to fill the concrete pores is lower than that of boiling-water.

It can be concluded that the porosity of the concrete showed growth in specimens immersed in boiling-water than those in cold-water. This is because in boiling water, they tend to expand and cause the air bubbles to get out from the pore/voids (Safiudin, 2005). In this case, FA and RHA showed lower permeability compared to porous SCCOPC and GGBS; and in SCC, the pore is more refined than normal concrete (Attiogbe, 2002). Nonetheless, lowest permeable porosity were observed in cold-water saturation technique.

Table5.3: Porosity of SCC

Mix	Compressive strength			Permeable porosity					
				Cold- water saturation %			Boiling-water saturation %		
	7d	28d	180d	7d	28d	180d	7d	28d	180d
SCCOPC	34	44	50	11.6	10.8	10.6	13	11.6	10.8
SCCFA15	38	49	69	7.07	6.93	6.6	7.13	7.07	6.93
SCCRH10	33	41	47	8.8	8.6	8.8	9.2	8.8	8.6
SCCGGBS5	28	40	45	10.8	10.5	10.3	11.2	10.8	10.5

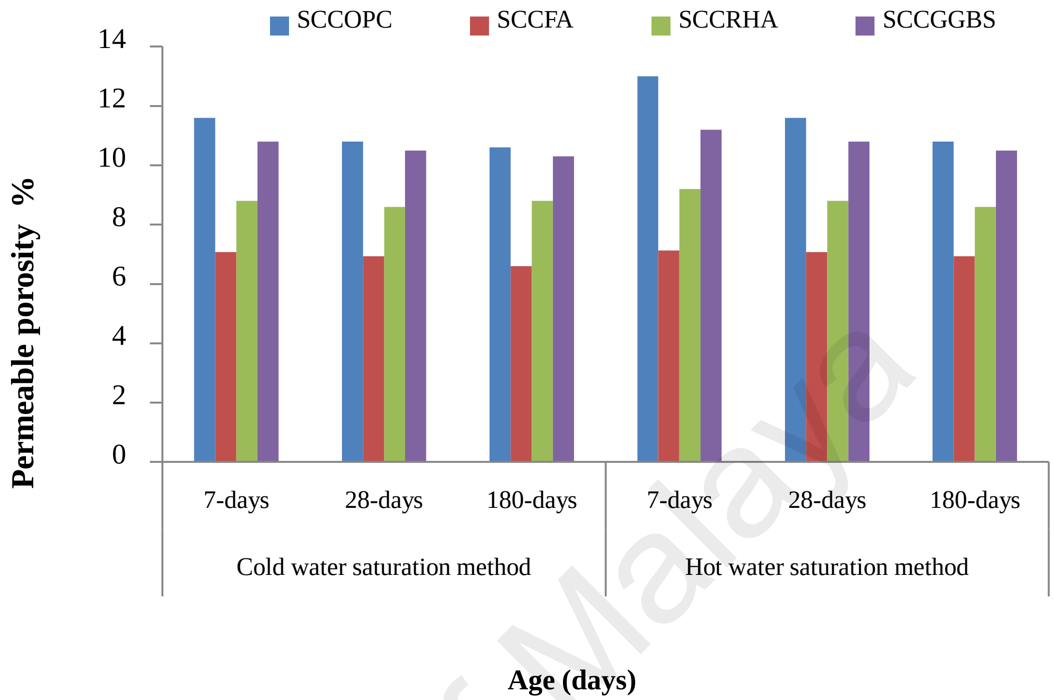

Figure 5.5: Permeable porosity of SCC measured by different saturation techniques.

5.3 Permeable porosity

When water enters the pore system of concrete, some water molecules are likely to be adsorbed to the hydrophilic hydration products. This may narrow the pore channels and impede further movement of water and air bubbles. The adsorption of water molecules could occur quite comfortably in a cold-water saturation technique. In boiling-water saturation technique, the adsorption of water molecules could be reduced by agitation due to heating, and thus, may enhance the release of air bubbles and the ingress of water (Safiuddin, 2005).

In this study, the efficacy of the adopted saturation techniques can be observed in Figures 5.6 and 5.7. It is proven from these figures that the cold water saturation technique is more efficient than the boiling-water saturation technique for measuring the permeable porosity of concrete

5.3.1 Hot and cold water methods

Cold-water saturation technique provided the lowest permeable porosity. Conversely, the boiling-water technique measured the highest permeable porosity as it is accounted for 10% to 12% higher permeable porosity than cold-water saturation (Safiuddin, 2005). Comparison of the correlation coefficient of the test indicated is high and confirms the durability development with the strength development.

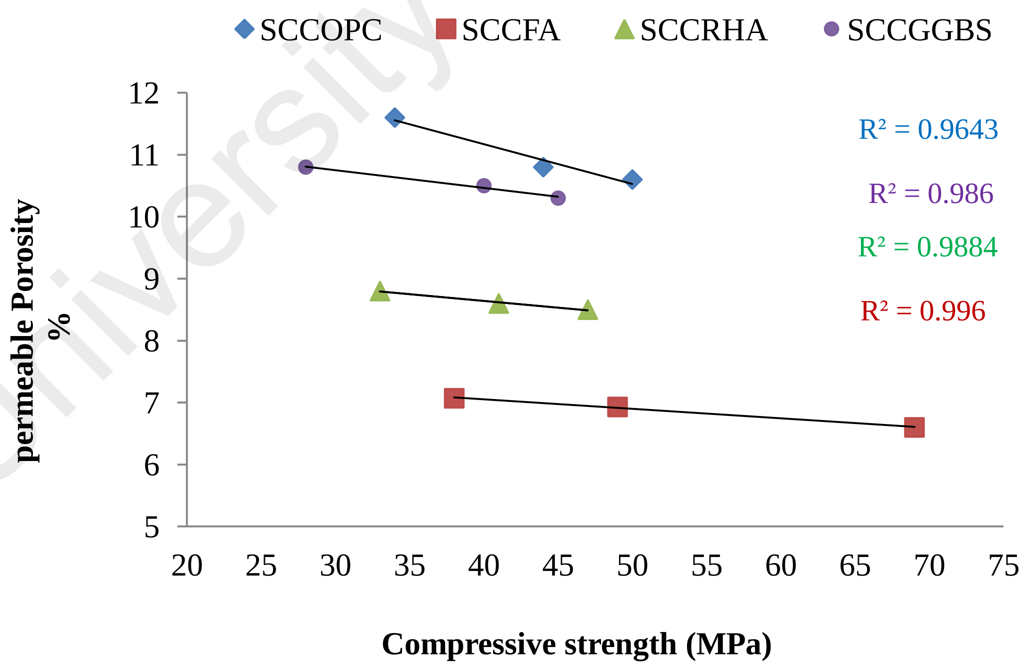

Figure 5.6: Development of permeable porosity using cold-water method with strength at deferent curing ages

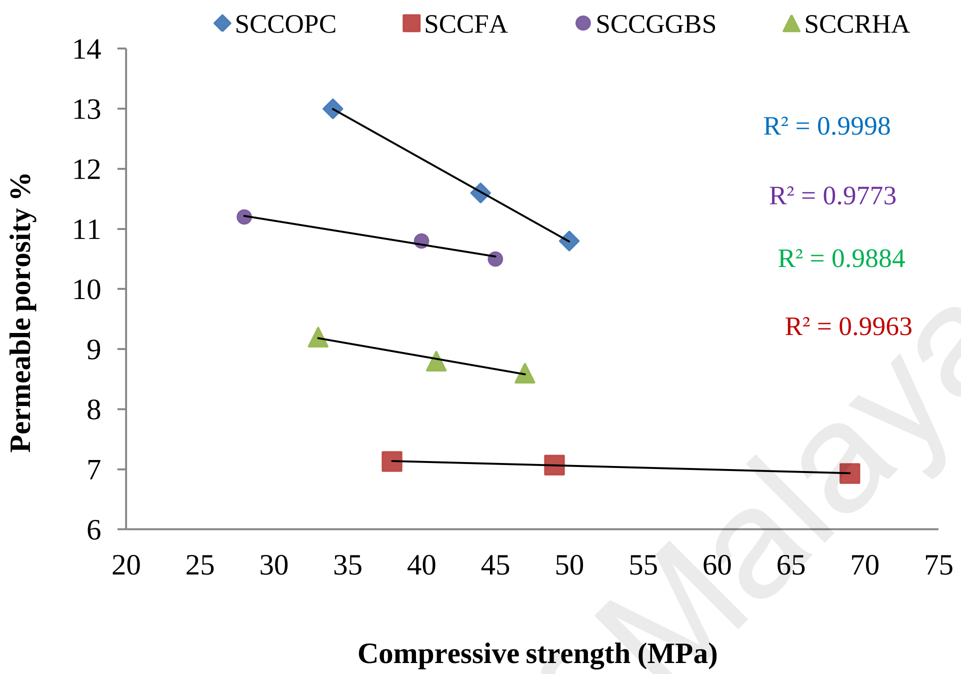

Figure 5.7: Development of permeable porosity using boiling-water

5.4 Non destructive tests

Figure 5.8 illustrates the effects of mixtures material on the ultrasonic pulse velocity (UPV) of SCC at different curing ages. The figure indicate that SCC mixtures containing SCM such as FA, RHA and GGBS, increases the UPV with the curing age increasing compressive strength. The three lines of SCC containing SCM such us FA, RHA and GGBS in Figure 5.9 demonstrated by best fit straight lines compared with control mix SCCOPC, indicating that when the compressive strength increases, the UPV also increases. The correlation coefficient indicated is high and equal to 0.8784, 0.8073, and 0.9994 respectively. This means the development of durability with the improvement of strength. The UPV test can be used to assess the strength of concrete there is a further limitation arising from the fact that the pulse travels faster through the water-filled void than through an air-filled one (Neville, 1995).

5.3.4.1 Ultrasonic pulse velocity (UPV) of SCC

Results shown in Table 5.4 indicate that the mixes containing SCM (FA, RHA and GGBS) are more homogenous for control mix SCCOPC than control mix SCOOPS. Hence, the UPV values are very high and acceptable. However, the UPV for a given aggregates and richness, is affected by changes in the hardened cement paste (Neville, 1995).

Table 5.4: UPV and compressive strength of SCC containing SCM

Mix. No	Ultrasonic pulse velocity m/s			Compressive strength (MPa)		
	28 d	90 d	180 d	28 d	90 d	180 d
SCCOPC	4.25	4.33	4.45	44	50	50
SCCFA15	4.35	4.41	4.59	46	59	69
SCCRHA10	4.41	4.65	4.67	41	44	47
SCCGGBS5	4.51	4.77	4.96	40	43	45

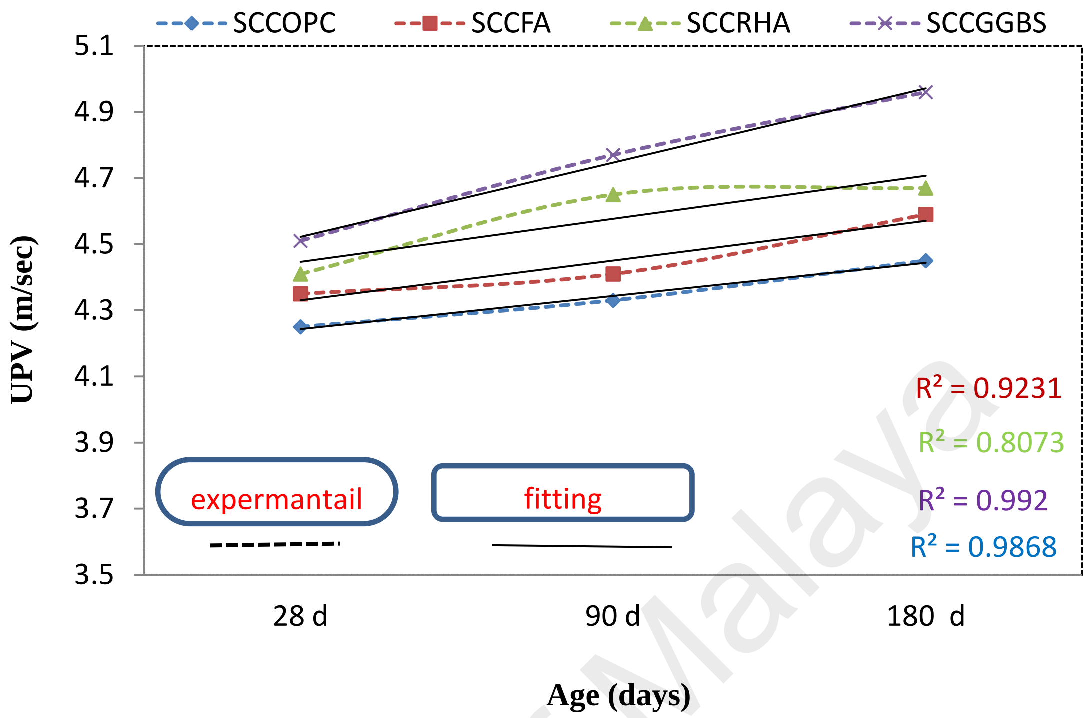

Figure 5.8: The relationship between UPV and curing ages of various SCC mixes

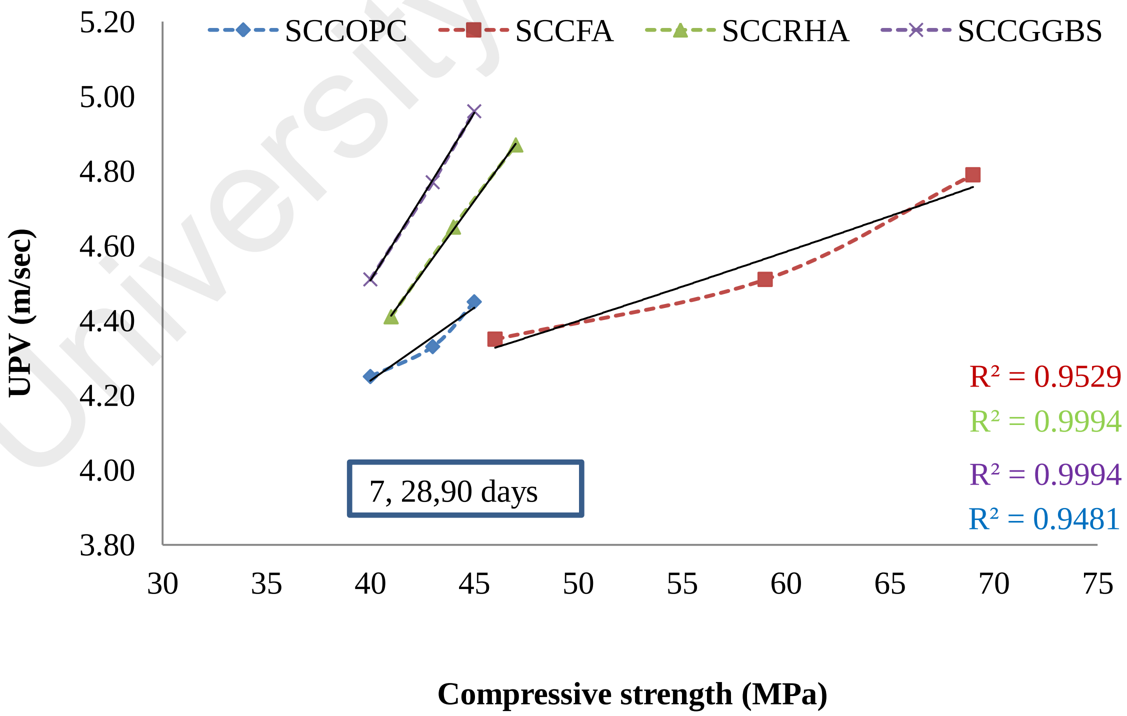

Figure 5.9: Development of UPV

5.5 Sulphate resistance of SCC concrete

The salt used in the study was magnesium sulphate (MS) hydrate dissolved in water with the content of 5 %. All specimens that were subjected to immersion in sulphate solution were initially cured in water for 7 days after demoulding. The effect of magnesium sulphate solution on the strength, length, and mass of samples at different curing ages using SCM containing FA, RHA, and GGBS with SCC are described below.

5.5.1 Effect of magnesium sulphate on SCC

The results illustrated in Table 5.4 and Figure 5.10 explains the compressive strength between the concrete immersed in MS and the standard curing of the concrete. The figures show the improvement of the strength immersed in MS relative to the strength of curing with water on all concrete mixed with the SCM products, such as FA, RHA, and GGBS. This can be attributed to the formation of the expansive ettringite in the presence of tricalcium aluminates inside the cement paste matrix and the infiltrated SO_4^+ ion, which resulted in filling the voids, and, thus, increasing the concrete maturity (Habeeb, 2010).

5.5.2 Effect of magnesium sulphate on strength

In this study, it is also observed that, from the compressive strength, the concrete specimens immersed in MS up to the third cycle (118d of sulphate exposure) for SCC containing FA exhibited higher values than others type of concrete containing RHA and GGBS because the SO_4^+ ion contents in FA mixes are higher than for the RHA and

GGBS mixes which voids to be filled and the strength to develop quicker, as explained in Table 5.5.

Findings on the effect of MS attack on cement paste showed higher compressive strength for specimens immersed in the $MgSO_4$ solution at room temperature for up to 118 d of sulphate exposure compared to controlled specimens (immersed in water). However, at later ages, adverse effect of sulphate on strength was dominant (Hekal, 2002).

Table 5.5: Effect of immersing SCC in MS on strength

Mix. No	Compressive strength / MPa						Relative strength $\frac{\text{Magnesium sulphate}}{\text{Water curing}}$ Ratio		
	Magnesium sulphate solution			Water curing					
	44 d	81 d	118 d	44 d	81 d	118 d	44 d	81 d	118 d
SCCOPC	42	44	48	40	42	46	1.05	1.05	1.04
SCCFA15	52	53	54	50	52	53	1.04	1.02	1.02
SCCRHA10	51	53	56	41	43	46	1.24	1.23	1.22
SCCGGBS5	52	53	54	47	48	49	1.11	1.10	1.10

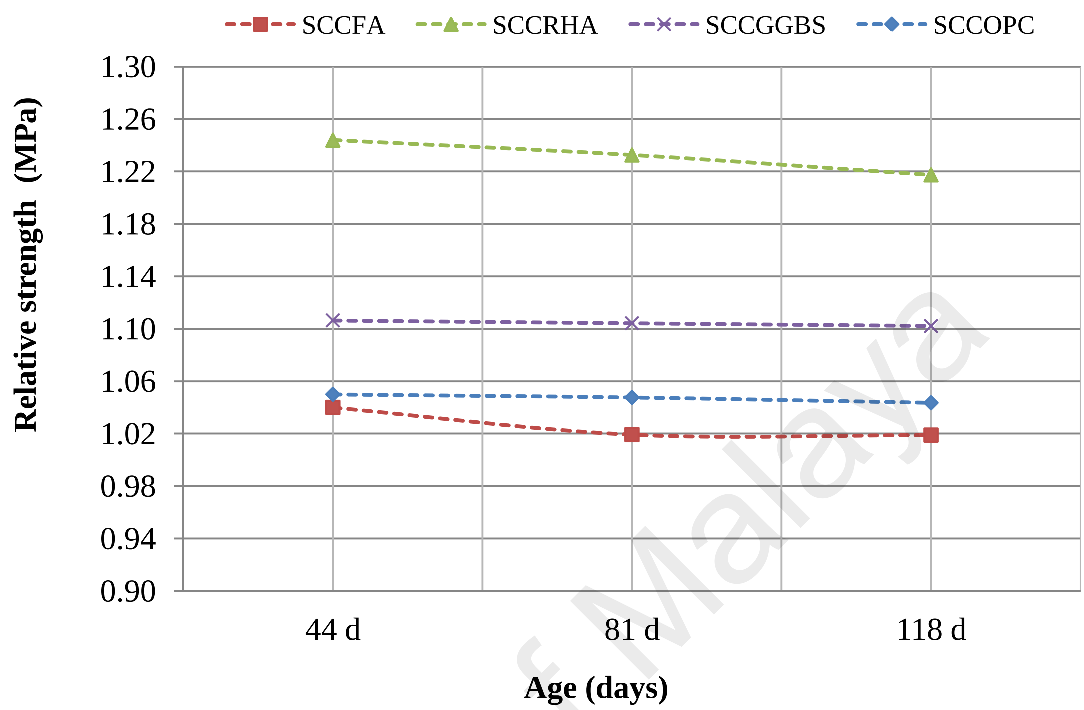

Figure 5.10: Effect of magnesium sulphate solution on strength Of SCC at 44, 81 and 118 d

Values of the compressive strength for the hardened concrete mixtures immersed in sulphate, “the control drying specimens” along with the relative compressive strength when tested at the same age are shown in Table 5.6. It can be observed that the relative strength of the concrete immersed in sulphate compared with air dried increased with concrete containing SCM such as FA, RHA, and GGBS in shorter time. For example, the relative strength for the 15 FA mixtures was 16% at the first cycle (37 days of sulphate exposure). However, in the third cycle (118 days), the value was reduced to 8%. In addition, the value of the relative strength also decreased for 10 RHA and 5 GGBS compared with SCCOPC.

Due to the increase of the binder material, it need to be treated with water that causing incomplete interaction between the components of the concrete, thus lead to shrinkage of concrete and affected the durability of concrete (Hekal, 2002).

Table 5.6: Effect of MS on the strength with air drying SCC

Mix. No	Compressive strength (MPa)						Relative strength $\frac{\text{Sulphate solution}}{\text{Air dried}}$s Ratio		
	Sulphate solution			Air dried					
	44 d	81 d	118 d	44 d	81 d	118 d	44 d	81 d	118 d
SCCOPC	42	44	48	39	41	44	1.08	1.07	1.09
SCCFA15	52	53	54	45	46	50	1.16	1.15	1.08
SCCRHA10	51	53	56	44	45	49	1.16	1.18	1.14
SCCGGBS5	52	53	54	43	45	47	1.21	1.18	1.15

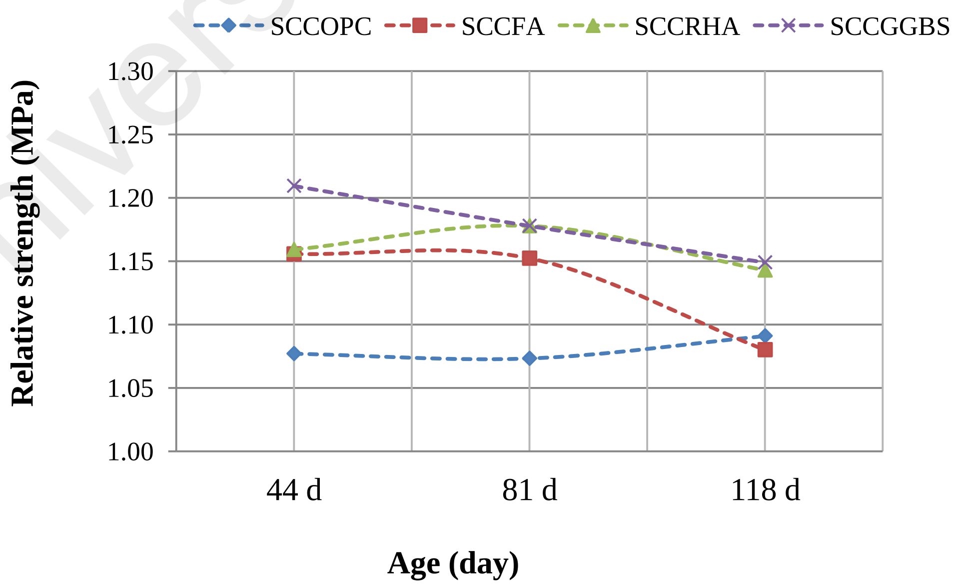

Figure 5.11: Compressive strength of air dried sulphate and concrete exposed to sulphate at different ages

5.5.3 Effect of magnesium sulphate on change in mass of SCC

The recorded average length and mass were expressed as percentage difference of mass and length with respect to the length and mass changes with the other samples left in the curing tank at same age and during the drying age as explained below.

The change in mass for the concrete exposures to sulphate up to 118 days compared with the mass stored in water and drying specimens in the laboratory taken at the end of three cycles i.e. 44d, 81d and 118 as shown in Figures 5.10 and 5.11. The results showed that the highest value of mass loss is recorded for the control mixture, which has a loss of mass at the curing case in the third cycle of display. The loss of mass for the 10 RHA, 15 FA and 5GGBS were less than the control mix; the RHA blended cement concrete results in better resistance to sulphate attack. Therefore, the mass loss can be used as a measure of sulphate attack due to the gypsum formation. Thus, the loss of mass is the best indicator to assess the degree of deterioration compared to changes in length and strength (Polivka & Brown, 1958).

The decreasing weight of all mixes that were left for air-dry is attribute to the formation of gypsum on the surface of concrete which also lead to the softening and spalling of the surface. Furthermore, shrinkage in FA, GGBS, and RHA were also influenced by the presence of SCM because of the surface area results in weight reduction (see Figures 5.12 and Table 5.13) and decreased in SCC as less water in the system.

In the drying test for all mixes, the reduced in weight is attributed to the formation of gypsum on the concrete surface which also results in the softening and decreasing of the concrete surface. In addition, the presence of SCM leads to more shrinkage in FA, GGBS and RHA respectively compared with normal mix. and The reason reduced the surface area of these materials, and thus, leads to reduce the weight.

Table 5.7: Effect of magnesium sulphate on change in mass of SCC

Mix. No	Mass (g)								
	Magnesium Sulphate solution immersing			Air curing			Water curing		
	44 d	81 d	118 d	44 d	81 d	118 d	44 d	81 d	118 d
SCCOPC	2220	2240	2240	2222	2206	2202	2274	2340	2425
SCCFA15	2460	2414	2402	2334	2332	2320	2480	2440	2480
SCCRHA10	2365	2353	2342	2272	2265	2200	2375	2368	2348
SCCGGBS5	2332	2320	2242	2246	2236	2220	2370	2362	2358

The drying shrinkage tends to decrease in SCC since a very small amount of free water is available in the system. SCC has minimum empty voids on the concrete surface that are largely responsible for drying shrinkage (Cusson, 2008)

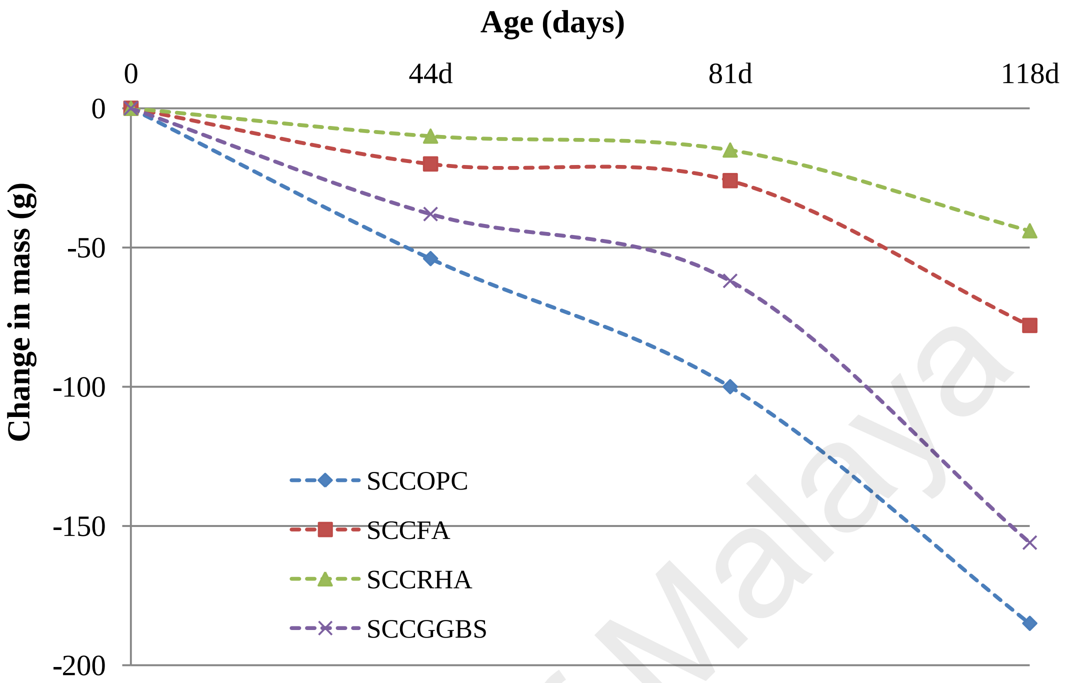

Figure 5.12: Effect of magnesium sulphate on change in mass for water curing SCC

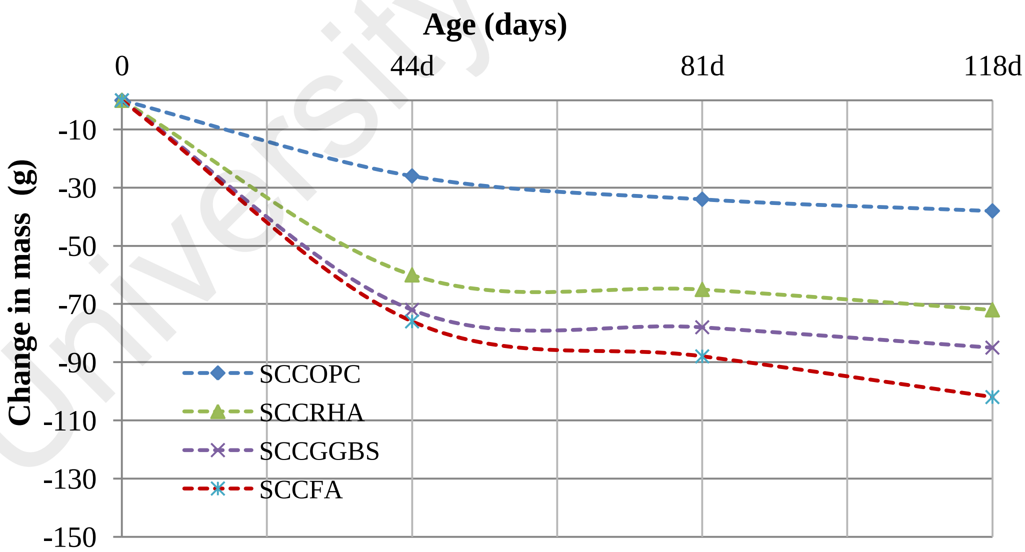

Figure 5.13: Effect of magnesium sulphate on change in mass for air dried SCC

5.5.4 Effect of magnesium sulphate on length change at SCC

Figures 5.14 and 5.15 depicted the expansion percentage of concrete exposed to sulphate for up to 118 days compared with the length of curing and drying for the same duration. As depicted, the expansion values are low and equal with the concrete immersed in magnesium sulphate because of the attribution of the normal concrete swelling. No correlations were observed between the amount of ettringite precipitation and expansion which has been proven experimentally and it is assumed that ettringite deposits in voids; therefore, exerts very little or no expansion (Kalousek, 1970)

Table 5.8 and Figure 5.14 illustrate the changes in the length between the concrete immersed in magnesium sulphate and concrete stored in water. It is found that the length changes in this study are relatively less for concrete immersed in magnesium sulphate and exposed that concrete containing SCM grade 40 exhibits less swelling in the volume of the concrete sample. This is because variations in the degree of fineness (particle size) causes the expansion to exhibit different behaviour of the SCM-containing mixes to close the voids in order to look better than the control mix OPC. Thus the shrinkage is increase with the increasing of cement content results in a large volume of hydrated cement paste (Neville, 1995). In addition, the changes in the length of concrete through air drying compared with the concrete immersed in magnesium sulphate exhibited the same behaviour as shown in Figure 5.15.

Table 5.8: Effect of magnesium sulphate on length change

Mix. No	Length at (mm)								
	Magnesium Sulphate solution			Water curing			Air drying		
	44d	81d	118d	44d	81d	118d	44d	81d	118d
SCCOPC	100.400	100.37	100.36	100.46	100.48	100.49	100.40	100.40	100.39
SCCFA	100.36	100.36	100.34	100.37	100.39	100.39	100.38	100.38	100.38
SCCRHA	100.38	100.34	100.34	100.42	100.42	100.46	100.4	100.37	100.39
SCCGGBS	100.39	100.39	100.34	100.42	100.45	100.42	100 .40	100 .40	100.39

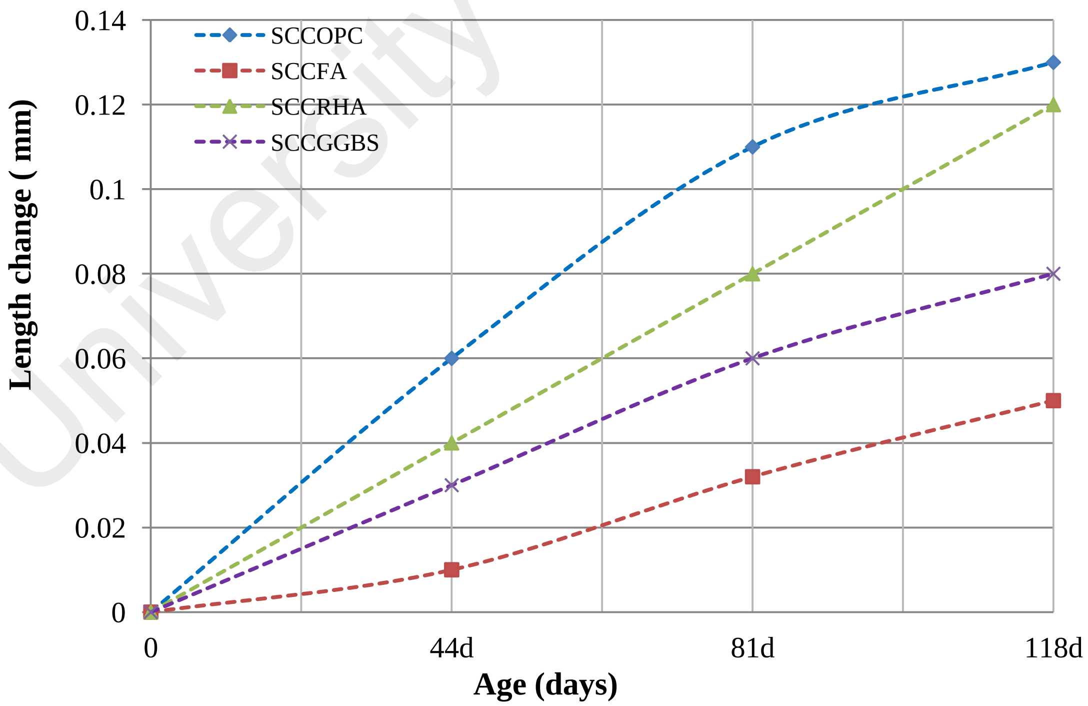

Figure 5.14: Effect of magnesium sulphate on length change at water curing SCC

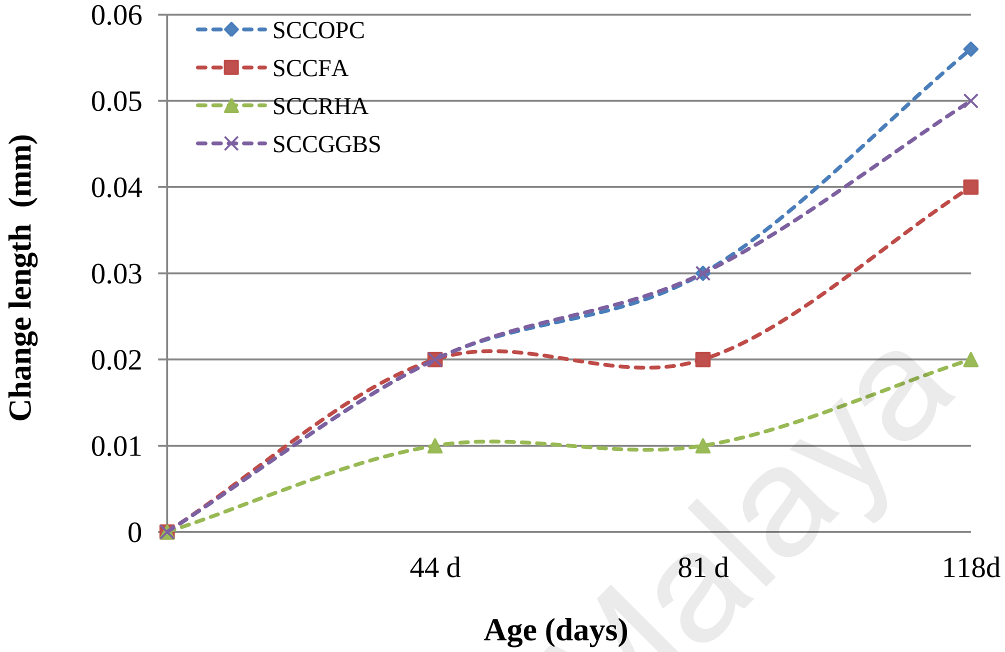

Figure 5.15: Effect of magnesium sulphate on length change of air drying SCC

5.6 Rapid chloride permeability (RCP) penetration of SCC

Chloride penetration of concrete is an important factor in classifying its durability. Generally, concrete with low chloride penetration will afford better protection to the reinforcement within it than the concrete with high water penetration. The chloride penetration resistance test (RCPT) can provide a good indication on the durability of SCC, and the section below explains the use of this test on SCC in more details.

5.6.1 Effect of SCC age on (RCP)

The results illustrated in Table 5.9 and Figure 5.16 show the development of RCP with increasing curing time. The concrete containing FA and RHA exhibited higher growth on the permeability than the concrete which contains GGBS. This is because of the ability is the result of the presence of a high percentage of pozzolan in the two types of concrete containing FA and RHA. It has also been shown that reactive RHA can be used to produce a good quality concrete with reduced porosity(Chindaprasirt, at el, 2005). In addition, the permeability of concrete containing palm oil fuel ash, rice husk-bark ash and fly ash are lower than that of OPC concrete (Chindaprasirt, 2007). There was a significant decreased in coulomb values due to FA and RHA replacement. This is again caused by a very high pozzolanic ratio which causes the concrete to also be more durable and homogeneous. For GGBS, smaller and softer particles are needed to allow for the closure of voids and to increase the homogeneity compared to normal SCC concrete (see Tables 3.3, 3.5 and 3.6 for chemical composition of SCM materials).

Table 5.9: Rapid chloride permeability of SCC containing SCM

Mix. No	RCPT (Coulombs)			Compressive strength (MPa)		
	28 d	90 d	180 d	28 d	90 d	180 d
SCCOPC	1674	985	736	42	46	50
SCCFA15	487	245	200	46	59	69
SCCRH10	562	337	253	41	44	47
SCCGGBS5	1513	637	367	40	43	45

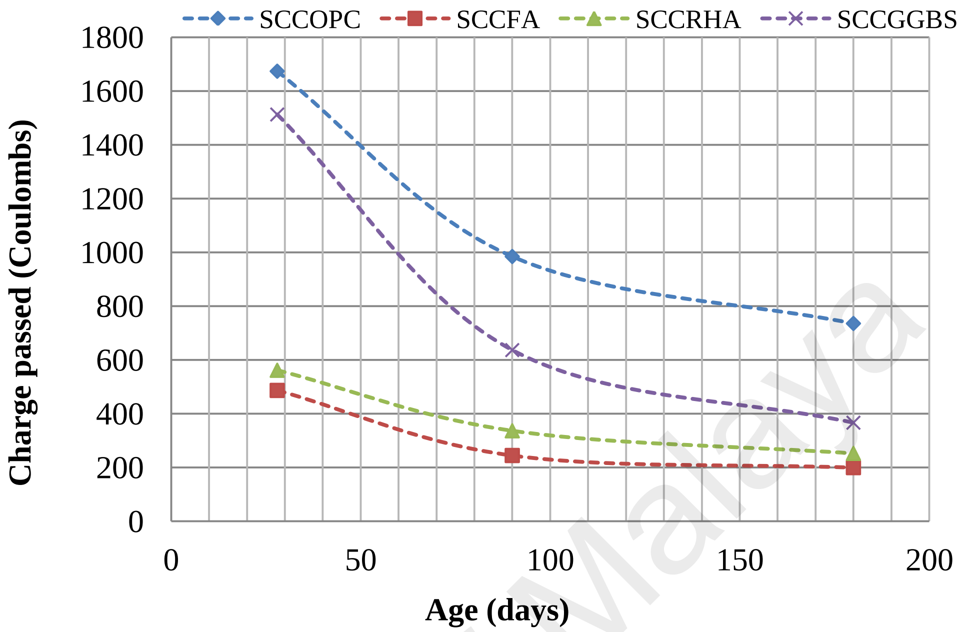

Figure 5.16: Effect of curing age on RCPT of SCC containing SCM

5.6.2 Effect of SCM type on RCP

Since the cement paste matrix pore structure is related to concrete penetrability, it is crucial to examine the chloride ingress rate into concrete which depends on the pore structure of the concrete, which is affected by factors including materials and age.

Results of this study showed that all SCM used gave greater amount of hydration and thus developed high pore structure which will affect the inclusion of SCM in the concrete.

According to McGrath et al (1997), aged concrete hydrates more and thus developed more pore structure and thus cause the SCM to close the pore efficiently and reduces the permeability of chloride on concrete Figure 5.17.

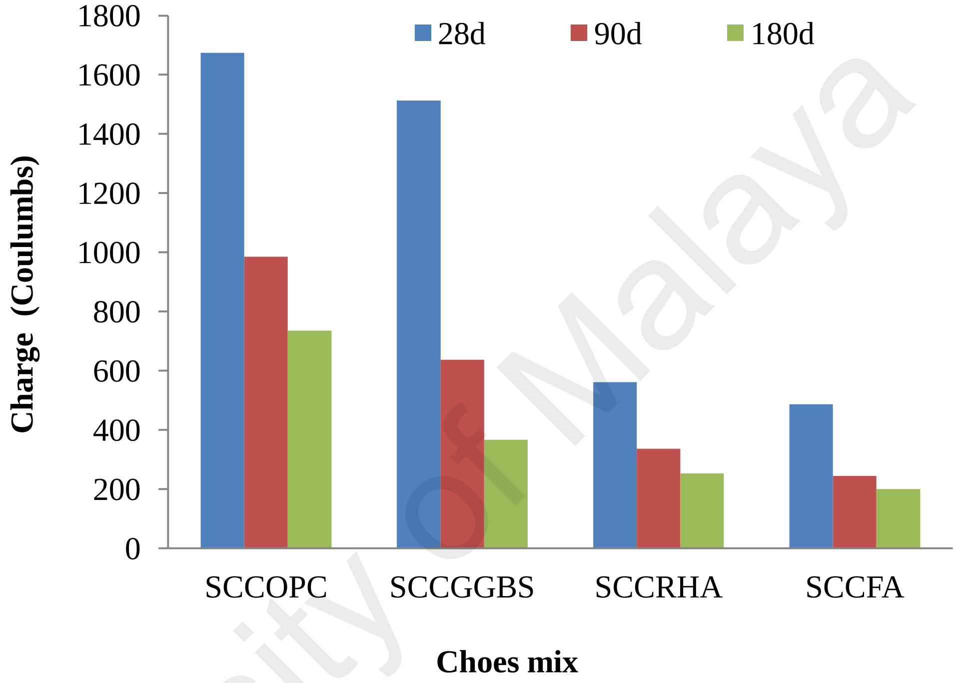

Figure 5.17: RCP of SCC containing various SCM at different age

5.6.3 Relationship between strength and RCP permeability

In this study, the SCM contributes to the improvement in the rapid chloride permeability (RCPT). The permeability of SCC containing FA, RHA and GGBS were lower than that of the content SCCOPC concrete, thereby improving the durability properties and lowering the porosity of the concrete.

Consequently, the experiments revealed that the development of RCPT is consistent with the development of compressive strength of concrete using various supplementary cementitious materials (SCM), especially when using FA and RHA, because the ratio of pozzolanic materials in FA and RHA is higher than in the GGBS, which means it is less porous compared to SCC containing GGBS and OPC. The ratio of silica in FA and RHA is higher than in concrete content GGBS based on chemical composition properties of the binder material. The results illustrated by Table 5.8 and Figure 5.18, show that there is a high correlation coefficient and equal to 0.91, 0.97, 0.96 and 0.93 for FA, RHA, GGBS and OPC concrete respectively.

With regard to permeability, the incorporation of pozzolanic products such as fly ash reduces the average pore size and results in a less permeable paste (Chindaprasirt, 2007) and (Blackburn, 1997). In summary, the excellent improvement in the resistance to chloride penetration using the blended pozzolans is probably due to the synergic effect of the blend of fine pozzolans (Isaia, 2003).

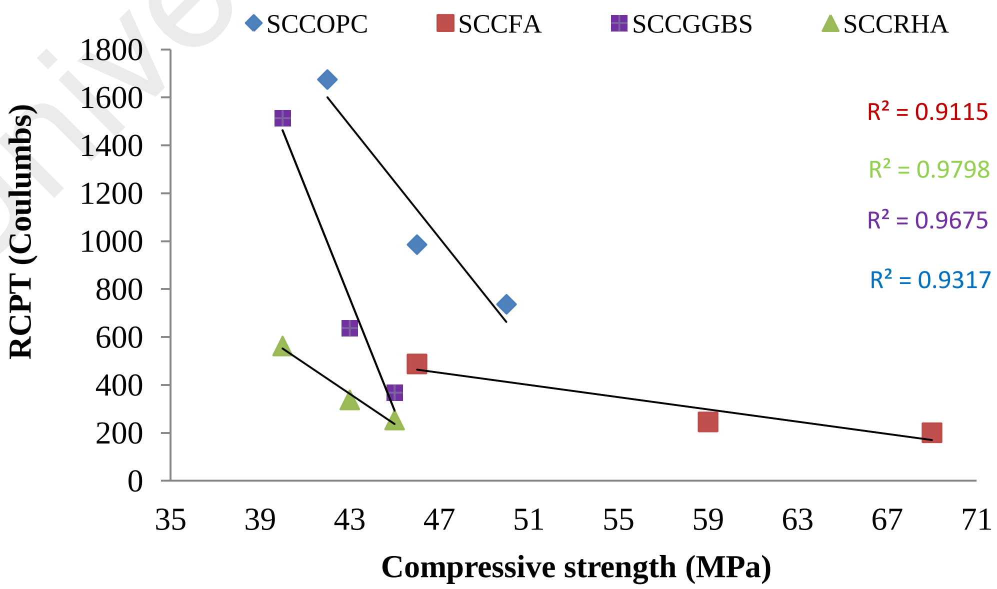

Figure5.18: RCP and strength of SCC at different curing age

CHAPTER 6: CONCLUSIONS

6.1 Introduction

The research investigates the properties of self compacting concrete (SCC) containing supplementary cementing materials such as fly ash (FA), rice husk ash (RHA) and ground granulated blast furnace slag (GGBS), which are available industrial and agricultural wastes found in Malaysia. The main findings, conclusions and recommendations for future works are presented in this chapter.

6.2 Physical properties of materials

Since the normal absorption of aggregate can be ignored in the design of a mix such as normal concrete, compensation for the water absorbed by aggregate is necessary. This can be done by drying the aggregate. Accurate mix design of concrete is only possible with proper characterization of its constituent materials. The characteristics of aggregates used in this work are as follows:

1. The maximum size of coarse aggregate was 12 mm according to the requirements of compressive strength and workability of self compacting concrete (SCC).

2. The SEM (Scanning Electron Microscopy) shows porous structure of RHA, because absorbs a high amount of water, leading to a reduction in workability and lower strength of the paste.

6.3 Mixture proportions and fresh properties of SCC mix

1. In general, the utilization of FA, RHA and GGBS waste in SCC was shown to be a good alternative to conventional building materials. The use of FA, RHA and GGBS in concrete can help to overcome the over-dependence on depleting resources, especially in the areas where the supplementary cementing materials are in abundant supply.

In addition, guidelines for optimization of mix proportions of SCC were established and a procedure for adjustment of mix proportions of SCC was proposed.

1. In order to obtain the SCC grade 40 MPa containing FA, RHA and GGBS, suitable replacement level is 15%, 10% and 5%.

2. Fine aggregate to coarse ratio of 55:45 give the highest strength and durability compared to ratio of 50:50 and 60:40

3. To achieve the target workability, the w/b needs to be adjusted and the type of superplasticizer used is important, especially with SCC.

4. Use of different binder ratio for SCM such as FA, RHA and GGBS lead to increase in fine materials ratio which work on closure of the voids and therefore produce homogeneous mix with minimal segregation

6. 4 Mechanical properties of hardened SCC with FA, RHA, and GGBS

1. 15%, 10% and 5% replacement of cement with FA, RHA, and GGBS respectively produced concrete of SCC properties.

2. Adding the SCM of FA, RHA, GGBS with normal SCC enhances the engineering properties such us the compressive strength, splitting, flexural and durability.

3 SCC mixes containing FA, RHA and GGBS exhibited higher compressive strength at 660 days compared to samples with SCM materials due to increased rate of pozzolanic reaction

4. Mix containing 15% FA shows the strength reduction factor (SRF) decreases by 5% compared to mix with 5% FA. The same trend is applicable for GGBS mix but not for RHA, which increases with increasing RHA content.

5. The variable space domain of SCM is classified into two subdivisions: greater than 5% SCM and less than 15% SCM. By using the equations below, SRF for FA increases with a rise in admixture content and augment the SCM content to 15%. The same applies to SRF for RHA and GGBS.

$$SRF = \begin{cases} 0.12\,p + 1, & \text{if } SCM \leq 15\% \\ -0.51\,p + 1.14, & \text{if } SCM \geq 5\% \end{cases}$$

Where:

p = powder ratio

6. Equations relating the modulus of rupture (*fr*) and compressive strength for SCC with various SCM such as FA, RHA and GGBS at 28 and 180 days was accorded. Equations below showed that the modulus of rupture of SCC containing SCM are compatible with equations of normal and high strength concrete:

$$fr = 0.60\sqrt{fc}$$ normal concrete

$$fr = 0.94\sqrt{fc}$$ high-strength concrete

Present work

$$fr_{SCCFA} = 0.97\sqrt{fc}$$ $R^2 = 0.97$

$$fr_{SCCRHA} = 0.97\sqrt{fc}$$ $R^2 = 0.97$

$$fr_{SCCGGBS} = 0.46\sqrt{fc}$$ $R^2 = 0.46$

7. The splitting tensile strength *(fsp)* for self compacting concrete containing supplementary cementitious material of grade 40 at 28 and 180 days is higher than normal SCC concrete. The equations are given as:

<u>At 28 days</u>

$fsp = 0.313\sqrt{fc}$ for - NC

$fsp = 0.578\sqrt{fc}$ for- SCCFA

$f_{sp} = 0.573\sqrt{fc}$ for- SCCRHA

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<u>At 180 days</u>

$f_{sp} = 0.461\, fc^{0.55}$ for - SCCFA

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8. The relationship between compressive strength and elastic modulus of concrete, Ec containing SCM (FA, RHA, and GGBS) and BS 8110 and ACI 318.99 depicted the interrelation among the three as follows

$Ec = 18.8\, f_{cu}^{0.15}$ $R^2 = 0.88$ containing SCM (present work)

$E_c = 9.1\, f_{cu}^{0.33}$ (BS8110)

$E_c = 4.23\, f_{cu}^{0.05}$ (ACI 318- 99)

9. Compared to normal SCC concrete, mixes containing SCM lead to improvement in flexural and splitting tensile at 180 days relative to 28 days. This is due to high ratio of silica content according to chemical composition of the materials used

10. Relatively larger coarse aggregate size were used in SCC mixes containing SCM and this leads to improvement in modulus of elasticity by approximately 5% compared to normal SCC. Relationship between elastic modulus and compressive strength of SCC mixes are as follows:

$$E\ sccopc = 0\ .000040\rho^{1.5}\sqrt{fc}$$

$$E_{SCCFA} = 0\ .000035\rho^{1.5}\sqrt{fc}$$

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11. The drying shrinkage at the early ages for mixes containing SCM (FA, RHA, GGBS) is higher than normal SCC because of the increasing ratio of the fine materials that filled most of the void and this lead to increase in the hardness of concrete and reduce the permeability of the concrete. The expansion of concrete is dependent on particle size and degree of fineness of SCM.

12. Expansion and shrinkage of SCC mixes subjected to water curing were improved due to SCM such as FA, RHA and GGBS compared to normal SCC. The expansion of FA and GGBS mixes is higher compared to RHA because RHA contains 90% Sio_2.

13. SCC mixes containing SCM, such as FA, RHA and GGBS, exhibited increase in strength with age, which bring about decrease in shrinkage because the voids in the mixes are filled with CSH gel much more compared to SCC containing OPC alone.

14. Improvement in strength of concrete under water curing compared to air dried concrete was observed because of the slow pozzolanic reaction between SCM and calcium hydroxide from cement hydration in concrete of air drying.

6.5 Durability of Hardened SCC containing FA, RHA and GGBS

1. Use of FA, RHA and GGBS in SCC mixes led to enhancement in the durability of concrete by reduction of the water absorption and initial surface absorption values when compared to normal SCC. All of the specimens have low absorption characteristics of less than 3%, compared with SCCOPC.

2. Irrespective of the age of the specimen, when compared with the control SCCOPC concrete, there is a marked reduction in the ISAT values of FA and GGBS mixes at 28 curing compared with RHA mix. This is because the SCC mix containing FA and GGBS have void filled up at a shorter time compared to RHA mix and this process is observed at all ages of the concrete mixes.

3. Immersing the specimens in boiling-water led to growth in the permeable porosity of SCC concrete. This is because the samples in boiling water tend to expand and this led the air bubbles to move out from the pore voids. FA and RHA showed lower permeability compared to the porous OPC and GGBS.

4. When the concrete specimens were immersed in magnesium sulphate solution up to the third cycle (111d of sulphate exposure) SCC mixes containing FA exhibited higher compressive strength compared with concrete containing RHA and GGBS because the SO_4+ ion in FA was higher than RHA and GGBS mixes and have void filled up at a shorter time.

5. It can be observed that the relative strength of the concrete immersed in sulphate solution compared with those exposed to air drying increased for SCC concrete containing FA, RHA, and GGBS in shorter time. The relative strength for the FA mixture was 16% at the first cycle (44 days of sulphate exposure). However, in the third cycle (118 days), the value was reduced to 2%. In addition, the value of the relative strength also decreased for RHA and GGBS mixes 18% and 6% respectively compared with SCCOPC.

6. In the sulphate resistance test, the presence of SCM led to higher shrinkage in FA, GGBS and RHA mixes compared to the control mix. In this test the reduction in weight is attributed to the formation of gypsum on the concrete surface which also results in the softening and spalling of the concrete surface.

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8. Development of chloride permeability of SCC containing SCM is consistent with the development of compressive strength especially when FA and RHA were used because the amount of silica Sio_2 in FA and RHA is higher than that in GGBS. Lower permeability was found in these concrete compared to the mix containing GGBS or control OPC

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