MECHANICAL AND DURABILITY PROPERTIES OF SELF COMPACTING CONCRETE CONTAINING RICE HUSK ASH

A thesis submitted in partial fulfilment of requirement for the award of degree of

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In

Structural Engineering

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DECLARATION

I, Divya Chopra, hereby declare that this thesis report entitled **"Mechanical and Durability properties of Self Compacting Concrete containing Rice Husk Ash"** submitted in the partial fulfilment of the requirements for the award of degree of Master of Engineering in Structural Engineering, in the Civil Engineering Department, Thapar University, Patiala, is wholly my own work. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

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ABSTRACT

Self-compacting concrete (SCC) is relatively a recent development in the construction world. SCC is defined basically by two properties: Deformability and segregation resistance. It flows under its own weight while remaining homogeneous in composition. This research is aimed at examining the feasibility of using Rice Husk Ash as supplementary cementitious material. In this research, the main variables are the proportion of rice husk ash (0%, 10%, 15%, 20%) and cement content. Parameters kept constant are the amount of fine aggregates, coarse aggregates, water, SP content, w/b ratio.

The primary aim of this study is to explore the feasibility of using rice husk ash as supplementary cementitious material in SCC by examining its fresh properties, mechanical properties (compressive strength, splitting tensile strength), durability properties (porosity, rapid chloride permeability), along with microstructure analysis with XRD and SEM.

The test results revealed that the fresh properties were significantly influenced by rice husk ash content. All the results were in range as per code specified. Mix 20RHA showed minimum workability.. The increase of about 25% strength at 7 days, 33% strength at 28 days and 36% strength at 56 days were observed with increase of RHA content from control mix (0RHA) to 15RHA. Maximum splitting tensile strength was also obtained by the mix 15RHA. Greatest increase in mechanical properties was observed for the mix containing 15% rice husk ash. The inclusion of rice husk ash as replacement of cement does not affect the strength properties negatively as the strength remains within limits up to 20% replacement. Inclusion of RHA showed great improvement in durability properties of concrete. All the mixes were less porous as compared to controlled mix with 0% rice husk ash and they showed low chloride penetration also. Microstructure of 15RHA mix shows dense formation of C-S-H gel that is the root cause for increase in strength.

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%	Percentage
min	Minutes
mm	Millimetre
cm	Centimetre
m	Meter
L	Litre
sec	Second
g/cm^2	Grams per centimetre square
cm^2/g	Centimetre square per gram
m^2/kg	Meter square per kilogram
w/b	Water/binder
Kg/m^3	Kilogram per meter cube
d	Days
MPa	Mega Pascal
h	Hour
^0C	Degree Celsius
c/c	Centre to centre
Φ	Diameter
N	Newton
KN	Kilo Newton

CHAPTER 1: INTRODUCTION

1.1 General

Cement-based materials are the most abundant of all man-made materials and are among the most important construction materials, and it is most likely that they will continue to have the same importance in the future. However, these construction and engineering materials must meet new and higher demands. When facing issues of productivity, economy, quality and environment, they have to compete with other construction materials such as plastic, steel and wood. One direction in this evolution is towards self-compacting concrete (SCC), a modified product that, without additional compaction energy, flows and consolidates under the influence of its own weight.

Self – compacting concrete (SCC) is a fluid mixture, which is suitable for placing in difficult conditions and also in congested reinforcement, without vibration. Development of self-compacting concrete (SCC) is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. In principle, a self – compacting or self – consolidating concrete must:

- Have a fluidity that allows self – compaction without external energy
- Remain homogeneous in a form during and after the placing process and
- Flow easily through reinforcement

Self compacting concrete is not affected by the skills of workers, the shape and amount of reinforcing bars or the arrangement of a structure and, due to its high-fluidity and resistance to segregation it can be pumped longer distances, (Bartos, 2000).

1.1.1 History behind development of self-compacting concrete

Modern application of self-compacting concrete (SCC) is focussed on high performance, better and more reliable and uniform quality. Self-compacting concrete, in principle, is not new. Special applications such as underwater concreting have always required concrete, which could be placed without the need for compaction, (Bartos, 2000). In such circumstances vibration was simply impossible. Early self compacting concretes relied on very high contents of cement paste and, once super plasticizers became available, they were added in the concrete mixes. The mixes required specialized and well-controlled placing methods in order to avoid segregation, and the high contents of cement paste made them prone to shrinkage. The overall costs were very high and applications remained very limited.

The introduction of “modern” self-levelling concrete or self-compacting concrete (SCC) is associated with the drive towards better quality concrete pursued in Japan around 1983, where the lack of uniform and complete compaction had been identified as the primary factor responsible for poor performance of concrete structures, (Dehn *et al*., 2000). Due to the fact that there were no practical means by which full compaction of concrete on a site was ever to be fully guaranteed, the focus therefore turned onto the elimination of the need to compact, by vibration or any other means. This led to the development of the first practicable SCC by researchers Okamura and Ozawa (1986) at the University of Tokyo and the large Japanese contractors (e.g. Kajima Co., Maeda Co., Taisei Group Co., etc.) quickly took up the idea. The contractors used their large in-house research and development facilities to develop their own SCC technologies. Each company developed their own mix designs and trained their own staff to act as technicians for testing on sites their SCC mixes. A very important aspect was that each of the large contractors also developed their own testing devices and test methods. In the early 1990‟s there was only a limited public knowledge about SCC, mainly in the Japanese language. The fundamental and practical know-how was kept secret by the large corporations to maintain commercial advantage. The SCCs were used under trade names, such as the NVC (Non-vibrated concrete) of Kajima Co., SQC (Super quality concrete) of Maeda Co. or the Biocrete (Taisei Co.). Simultaneously with the Japanese developments in the SCC area, research and development continued in mix-design and placing of underwater concrete where new admixtures were producing SCC mixes with performance matching that of the Japanese SCC concrete (e.g. University of Paisley / Scotland, University of Sherbrook/Canada), (Ferraris,1999). SCC has proved beneficial economically because of a number of factors as noted below, (Krieg, 2003 and ENFARC, 2002):

- Faster construction,
- Reduction in site manpower,
- Easier placing,
- Uniform and complete consolidation,
- Better surface finishes,
- Improved durability,
- Increased bond strength,
- Greater freedom in design
- Reduced noise levels, due to absence of vibration, and
- Safe working environment.

1.1.2 Motive behind development of self-compacting concrete

Recognising the lack of uniformity and complete compaction of concrete by vibration, researchers at the University of Tokyo, Japan, started in late 1980’s to develop Self compacting concrete. By the early 1990’s, Japan has developed and used SCC that does not require vibration to achieve full compaction. By the year 2000, the SCC has become popular in Japan for prefabricated products and ready mixed concrete. The utilisation of self compacting concrete started growing rapidly.

The other aim was to reduce durability problems in complicated and heavily reinforced concrete structures due to lack of skilled workers and a poor communication between designers and construction engineers.

As a result of this fact, one solution for the achievement of durable concrete structures independent of the quality of construction work was the employment of self-compacting concrete, which could be compacted into every corner of a formwork, purely by means of its own weight. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, were carried out by researchers Ozawa and Maekawa at the University of Tokyo, (Bartos, 2000). During their studies, they found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate consolidation of the concrete in the casting operations. By developing concrete that self-consolidates, they eliminated the main cause for the poor durability performance of the concrete.

1.1.3 Construction incorporating self compacting concrete

By employing self-compacting concrete, the cost of chemical and mineral admixtures is compensated by the elimination of vibrating compaction and work done to level the surface of the normal concrete, (Khayat *et al*., 1997). However, the total cost for a certain construction cannot always be reduced, because conventional concrete is used in a greater percentage than self-compacting concrete. SCC can greatly improve construction systems previously based on conventional concrete requiring vibrating compaction. Vibration compaction, which can easily cause segregation, has been an obstacle to the rationalization of construction work. Once this obstacle has been eliminated, concrete construction could be rationalized and a new construction system, including formwork, reinforcement, support and structural design, could be developed.

The main reasons for the employment of self-compacting concrete can be summarized as follows:

- To shorten construction period.
- To assure compaction in the structure - especially in confined zones where vibrating compaction is difficult.
- To eliminate noise due to vibration - effective especially at concrete products plants.

The method for achieving self-compact ability involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the confined zone reinforcing bars (Okamura and Ouchi, 2003).

Okamura and Ozawa (2003) have employed the following methods to achieve self-compact ability:

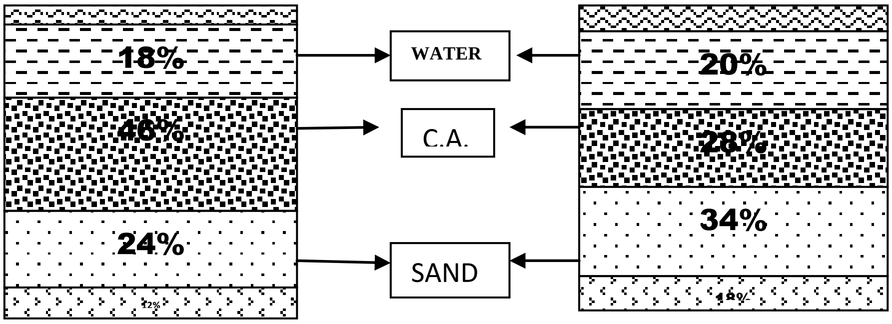
- Limited aggregate content
- Low water-powder ratio
- Use of super plasticizer

Because of the addition of a high quantity of fine particles, the internal material structure of SCC shows some resemblance with high performance concrete having self compact ability in fresh stage, no initial defects in early stage and protection against external factors after hardening.

Due to the lower content of coarse aggregate, however, there is some concern that:

- SCC may have a lower modulus of elasticity, which may affect deformation characteristics of pre stressed concrete members and
- Creep and shrinkage will be higher, affecting pre stress loss and long-term deflection (Mata, 2004).

Self compacting concrete can be produced using standard cements and additives. It consists mainly of cement, coarse and fine aggregates, and filler, such as fly ash or Super pozzolans, water, super plasticizer and stabilizer. The composition of SCC is similar to that of normal concrete but to attain self flow ability admixtures, such as fly ash, glass filler, limestone powder, silica fume, Rice husk ash, Super pozzolans etc; with some super plasticizer is mixed. *Figure 1.1* shows the comparison of traditional and SCC constituents.



Traditional Concrete

Self Compacting Concrete

Figure 1.1: Comparison of Traditional and SCC constituents

Three basic characteristics that are required to obtain SCC are:

- **High deformability** - related to the capacity of the concrete to deform and spread freely in order to fill all the space in the formwork. It is usually a function of the form, size, and quantity of the aggregates, and the friction between the solid particles, which can be reduced by adding a high range water-reducing admixture (HRWR) to the mixture.

- **Restrained flow ability** - represents how easily the concrete can flow around obstacles, such as reinforcement, and is related to the member geometry and the shape of the formwork.
- **A high resistance to segregation** - related to the cohesiveness of the fresh concrete, which can be enhanced by adding a viscosity-modifying admixture (VMA) along with a HRWRA, by reducing the free-water content, by increasing the volume of paste, or by some combination of these constituents. (Khayat *et al*., 2004). *Figure 1.2* shows basic principles for the production of SCC.

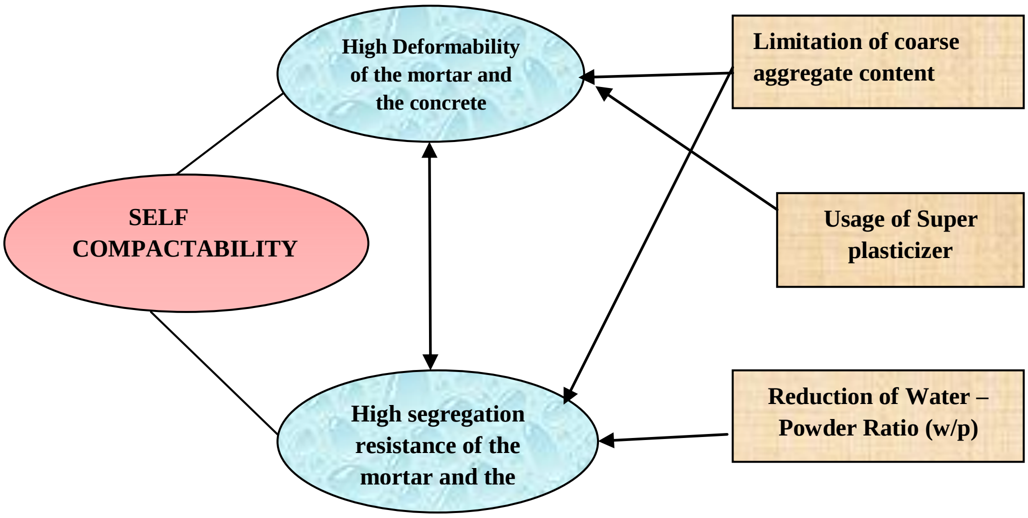


Figure 1.2: Basic principles for the production of SCC (Dehn *et al*., 2000)

1.1.4 World-wide current scenario of self-compacting concrete

Self-compacting concrete has already been used in several countries. In Japan, major construction projects included the use of SCC in the late ’90s. Today, in Japan, efforts are being made to free SCC of the “special concrete” label and integrate it into day-to-day concrete industry production (Okamura, 1997). Currently, the percentage of self-compacting concrete in annual product of ready-mixed concrete (RMC), as well as precast concrete (PC), in Japan is around 1.2% and 0.5% of concrete products.

In the United States, the precast industry is also leading SCC technology implementation through the Precast/Pre stressed Concrete Institute (PCI) which has done some research on the use of SCC in precast/pre stressed concretes starting with 1999 (Bartos, 2000). It is estimated that the daily production of SCC in the precast/pre stressed industry in the United States will be 8000 m^3 in the first quarter of 2003 (around 1% of the annual ready-mix concrete). Furthermore, several state departments of transportation in the United States (23 according to a recent survey) are already involved in the study of SCC (Bartos, 2000). With such a high level of interest from the construction industry, as well as manufacturers of this new concrete, the use of SCC should grow at a tremendous rate in the next few years in the United States. However, even if it is made from the same constituents the industry has used for years, the whole process, from mix design to placing practices, including quality control procedures, needs to be reviewed and adapted in order for this new technology to be applied properly.

The introduction of the SCC in Europe is largely connected with the activities of the international association RILEM, France, particularly of its Technical Committee TC145-WSM on “Workability of Fresh Special Concrete Mixes” (Dhir *et al.*, 1999). The TC145-WSM was founded in 1992 and immediately attracted expert memberships from all over the world. The aim was to look at the production stage of a number of “special” concretes and identify workability parameters and other characteristics of the mixes in their fresh state that governed the reliable and economical achievement of the “special” or “high-performance” parameters the concretes offered. As the importance of the SCC became widely recognized, other European countries, Germany, Sweden, UK, Denmark, Netherlands, Norway, Finland, etc., have decided to keep up with the developments in this area. For example, in Sweden, the SCC market share was at five percent in RMC and PC in 2002, and was expected to double in 2003. Housing and tunnelling, as well as bridge construction for the Swedish National Road Administration were the main areas of use for SCC. In the Netherlands and Germany, the precast industry is mainly driving the development of SCC, with an expected eight percent of market share in 2003 in Netherlands.

Today, self-compacting concrete is being studied worldwide, with papers presented at almost every concrete-related conference, but until now - year 2003 - there is no universally adopted standardized test method for evaluation of self-compact ability of this concrete. Currently, the use of self-compacting concrete is being rapidly adopted in many countries. The use of self-compacting concrete should overcome concrete placement problems associated with the concrete construction industry. However, there still is a need for conducting more research and development work for the measurement and standardization of the methods for the evaluation of the self-compacting characteristics of SCC.

1.2 Benefits and Advantages

At present self compacting concrete (SCC) can be classified as an advanced construction material. The SCC as the name suggests, does not require to be vibrated to achieve full compaction. This offers benefits and advantages over conventional concrete.

- Improved quality of concrete and reduction of onsite repairs.
- Faster construction times.
- Lower overall costs.
- Facilitation of introduction of automation into concrete construction. Improvement of health and safety is also achieved through elimination of handling of vibrators.
- Substantial reduction of environmental noise loading on and around a site.
- Possibilities for utilization of “dusts”, which are currently waste products and which are costly to dispose of.
- Better surface finishes.
- Easier placing.
- Thinner concrete sections.
- Greater Freedom in Design.
- Improved durability, and reliability of concrete structures.

- Ease of placement results in cost savings through reduced equipment and labour requirement.
- SCC makes the level of durability and reliability of the structure independent from the existing on site conditions relate to the quality of labour, casting and compacting systems available.
- The high resistance to external segregation and the mixture self – compacting ability allow the elimination of macro – defects, air bubbles, and honey combs responsible for penalizing mechanical performance and structure durability.

1.3 SRM's – Secondary Raw Materials

SRM's are basically supplementary cementitious materials, fillers, powders depending upon their role in fresh and hardened state. They are less energy intensive materials, industrial byproduct that requires less or no processing. They themselves posses little or no cementitious value but will in finally divided form and in presence of moisture reacts with cement at ordinary temperature to form compounds possessing cementitious properties. SRM's helps in advancement of hydration and especially in improving the hydration product. They usually replace part of cement. These basically include limestone powder (LSP), fly ash (FA), ground granulated blast furnace slag (GGBS), silica fumes (SF) and rice hush ash (RHA). SRM's are also called mineral admixtures, contributing towards properties of hardened concrete through physical and chemical properties including hydraulic or pozzolanic activity. These materials react chemically with calcium hydroxide released from hydration of Portland cement to form cement compounds. These materials often added to concrete to make concrete mixtures more economical, reduce permeability, increase strength or influence other concrete properties.

1.3.1 Advantages of using SRM's

The use of supplementary cementing materials can significantly improve durability properties, transport properties of concrete. However different dosages and combinations of supplementary materials yield dramatically different results. The use of SRM's in concrete may bring lot's of benefits like increased flow and strength, decreased shrinkage , reduced water demand (WD) etc. but some problems may also be caused. A careful decision has to be made regarding selection of amount and type of SRM for particular application. In general SRM has both negative as well as positive effect on water demand, temperature rise, strength development, freeze- thaw resistance, chemical attack resistance etc. They also have effect on volume stability and microstructure. With continuously graded aggregates the use of SRM's in the presence of super-plasticizers usually result in minimizing the voids, paste and hence the cement requirement. They also add to stability of the system. This could result in increased economy, high performance and increased durability

1.3.2 Role of SRM's in strength enhancement

Inert and pozzolanic admixtures modify the physical and chemical properties of mortars and concrete and the compressive strength can be separated into fractions of strength related to physical and chemical effects of mineral admixtures. When mineral admixtures are added three effects are quantified including dilution, heterogeneous nucleation (physical) and pozzolanic reaction (chemical) depending on amount and solubility of amorphous silica. Heterogeneous nucleation is a physical process leading to chemical activation of hydration of cement such that mineral admixture particles acts as nucleation centers for hydrates thus enhancing cement hydration. A smaller amount of powder has an optimum efficiency and results in large increase in compressive strength while use of large amount of powder has little effect.

1.3.3 Use of rice husk ash as filler material

Pozzolans from agricultural waste are receiving more attention now since their uses generally improve the properties of the blended cement concrete, and reduce the environmental problems. Palm oil fuel ash and rice husk ash are two promising pozzolans and are available in many parts of the world. (Chindaprasirt *et al.*, 2008)
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 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 rice husk ash is a highly siliceous material that can be used as an admixture in concrete if the rice husk is burnt in a specific manner. The characteristics of the ash are dependent on the components, temperature and time of burning, (Hwang, 1985).

Rice husk is also abundant in many parts of the world. When properly burnt at temperature lower than 700 °C, reactive amorphous silica is obtained, (Chindaprasirt *et al.*, 2008). The silica content in rice husk ash is high at approximately 90%. Silica in amorphous form is suitable for use as a pozzolan. With proper burning and grinding, ground rice husk ash (RHA) can be produced and used as a pozzolan. Even for higher burning temperature with some crystalline formation of silica, good RHA can still be obtained by fine grinding (Chindaprasirt *et al.*, 2008). The reactive RHA is used to produce good quality concrete with reduced $Ca(OH)_2$ and higher resistance to sulphate attack, (Chindaprasirt *et al.*, 2008).

1.4 Tests and Properties

1.4.1 Properties

Fresh SCC must possess at required levels the following key properties:

- **Filling ability:** This is the ability of the SCC to flow into all spaces within the formwork under its own weight.
- **Passing ability:** This is the ability of the SCC to flow through tight openings such as spaces between steel reinforcing bars, under its own weight.
- **Resistance to segregation:** The SCC must meet the required levels of properties A & B whilst its composition remains uniform throughout the process of transport and placing.

  Figure 1.3 shows schematic ways to achieve SCC.

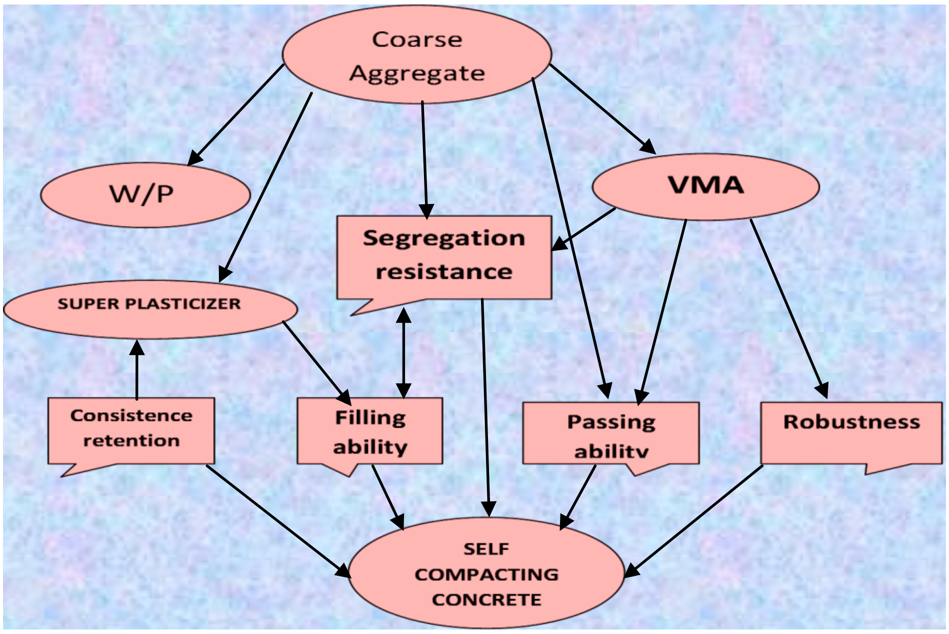


Figure 1.3: Schematic ways to achieve SCC

1.4.2 Tests

Some of the important tests conducted on fresh SCC to evaluate its workability are summarized in *Table 1.1* and are briefly explained later.

Table 1.1: Test methods to evaluate the workability properties of SCC (EFNARC, 2002)

Property	Test Methods	
	Field (Quality Control)	
Filling Ability	Slump Flow Test T_{50cm} Flow Test V- Funnel Test Orimet Test	Slump Flow Test T_{50cm} Flow Test V- Funnel Test Orimet Test
Passing Ability	L-Box Test U-Box Test Fill Box Test	J Ring Test
Segregation Resistance	GTM Test V-Funnel At $T_{5\ Mins}$	GTM Test V-Funnel At $T_{5\ Mins}$

1.4.2.1 Slump flow test

The slump flow test is used to assess the horizontal free flow of self compacting concrete in the absence of obstructions. The equipments used are the same as for the conventional Slump test. The test method differs from the conventional one by the fact that the concrete sample placed into the mould is not rodded and when the slump cone is removed the sample collapses, (Ferraris, 1999). The diameter of the spread of the sample is measured, i.e. a horizontal distance is determined as opposed to the vertical distance in the conventional Slump test. The Slump Flow (*Figure 1.4*) test can give an indication as to the consistency, filling ability and workability of SCC. The SCC is assumed of having a good filling ability and consistency if the diameter of the spread reaches values between 650 mm to 800 mm, (EFNARC, 2002).

Figure 1.4: Slump flow test (Zhimin *et al*., 2008)

1.4.2.2 U- box test

Of the many testing methods used for evaluating self-compact ability, the U- box test *(Figure 1.5)* proposed by the Taisei group is the most appropriate, due to the small amount of concrete used, compared to others, (Ferraris, 1999). This test is used to measure the filling ability of SCC. The apparatus consists of a vessel that is divided by a middle wall into two compartments. It provides a good direct assessment of passing ability.

For conducting the U-box test, one of the compartments of the apparatus is filled with the concrete sample and filled concrete is left to stand for 1 minute. Then the sliding gate is lifted to allow the concrete to flow out into the other compartment. After the concrete comes to rest, the height of the concrete in the compartment that has been filled is measured in two places and the mean height (H1) is calculated. Also the height in the other compartment (H2) is measured. The filling height is then calculated as H1- H2. The whole test has to be performed within 5 min. If the concrete flows as freely as water, at rest it will be horizontal, so H1- H2 = 0. Therefore, the nearer this test value, i.e., the filling height', is zero, the better the flow and passing ability of SCC (EFNARC, 2002).

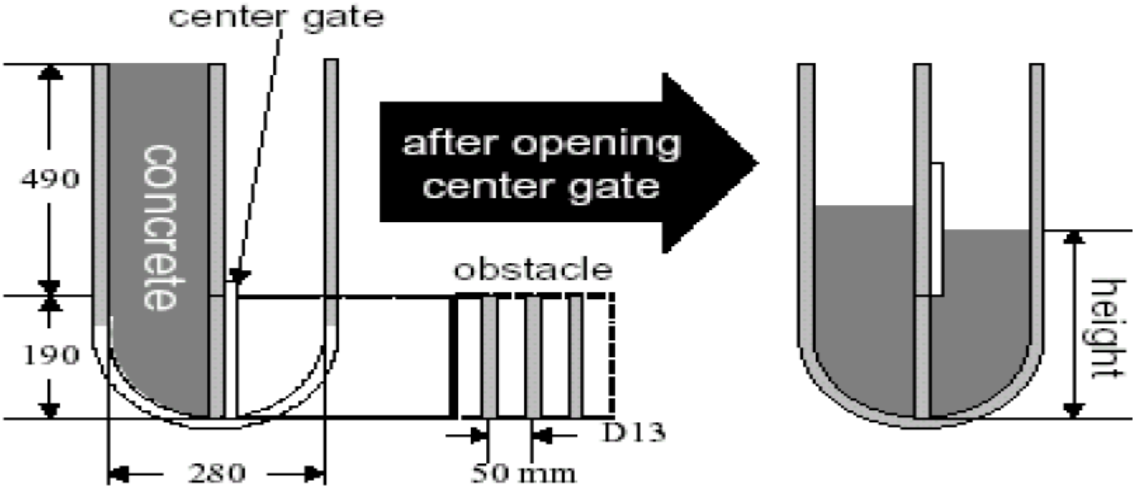


Figure 1.5: U- box test (Ouchi *et al.*, 2000)

1.4.2.3 Orimet test

This test is based on the principle of an orifice rheometer applied to fresh concrete, (Bartos, 2000). The test involves recording of time that it takes for a concrete sample to flow out from a vertical casting pipe through an interchangeable orifice attached at its lower end. The shorter the Flow-Time, the higher is the filling ability of the fresh mix. The Orimet test also shows potential as a means of assessment of resistance to segregation on a site.

1.2.4.4 L- box test

This method uses a test apparatus comprising of a vertical section and a horizontal trough *(Figure 1.6)* into which the concrete is allowed to flow on the release of a trap door from the vertical section passing through reinforcing bars placed at the intersection of the two areas of the apparatus, (Dietz *et al*., 2000). The time that it takes the concrete to flow a distance of 200mm and 400mm into the horizontal section is measured, as is the height of the concrete at both ends of the apparatus (H1 & H2). The L-Box test can give an indication as to the filling ability and passing ability.

Figure 1.6: L- Box, (Google – Images for SCC)

1.2.4.5 V-funnel test

Viscosity of the self-compacting concrete is obtained by using a V-funnel apparatus, which has certain dimensions *(Figure 1.7)* in order for a given amount of concrete to pass through an orifice (Dietz *et al*., 2000). The amount of concrete needed is 12 L and the maximum aggregate diameter is 20 mm. The time for the amount of concrete to flow through the orifice is being measured. If the concrete starts moving through the orifice, it means that the stress is higher than the yield stress therefore; this test measures a value that is related to the viscosity. If the concrete does not move, it shows that the yield stress is greater than the weight of the volume used.

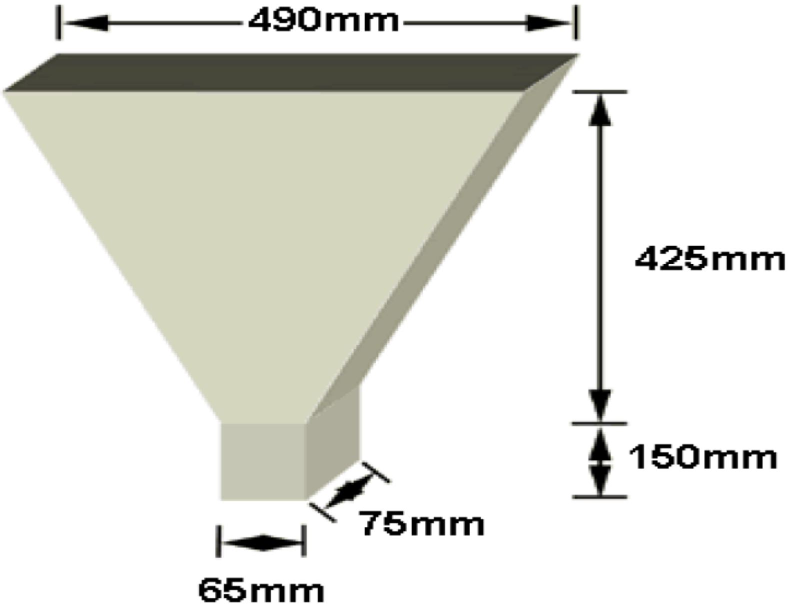


Figure 1.7: V-Funnel (Dietz *et al*., 2000)

In order to ensure that the SCC has not lost its uniformity during transport and placing due to its highly flow able and self levelling nature, it is suggested that the in-situ tests, such as rebound hammer, pull-out, etc. should be conducted. Non-variations in these near-surface properties may be considered as an indication of no loss of uniformity (Zhu *et al*., 2001).

The size and quantity of coarse aggregates in a SCC mixture are directly related to the concrete passing ability. The passing ability requirements depend on the formwork geometry and the extent of congestion of the reinforcement. Risk of blockage is reduced by providing adequate viscosity.

Adequate cohesiveness can be obtained by incorporating a viscosity-modifying admixture (VMA) along with a high range water reducing admixture to control bleeding, segregation, and surface settlement (Khayat *et al.*, 1997).Typical acceptance criteria for SCC with a maximum aggregate size of up to 20 mm are presented in *Table 2.2.*

Table 1.2: Acceptance criteria for Self-compacting Concrete, (EFNARC, 2002)

Method	Unit	Minimum Value	Maximum Value
Slump Flow	mm	650	800
J- Ring	mm	0	10
V- Funnel	sec	6	12
L- Box	(H2/H1)	0.8	1.0
U-Flow	(H2-H1) mm	0	30
Orimet	sec	0	5
Fill Box	%	90	100

1.5 Orientation of Thesis Report

This thesis is presented in five chapters as detailed below:

Chapter-1 Gives the introduction about self-compacting concrete, rice husk ash.

Chapter-2 Literature review presents the work done by various researchers in the field of Self- Compacting Concrete.

Chapter-3 Details the scheme of experimentation, materials used, and variables involved, concrete mixes, mix design, casting and testing of specimens.

Chapter-4 Gives results of various parameters studied and are compared with control concrete.

Chapter-5 Gives the major conclusions made in the study.

References

CHAPTER-2 LITERATURE REVEIW

2.1 Physical and Chemical Properties of Cement and RHA

Various scientists have studied the physical and chemical properties of both the materials i.e. ordinary Portland cement and rice husk ash. Physical and chemical properties of OPC are shown in *Table 2.1* and *Table 2.2.*

Table 2.1: Chemical Composition limits of Portland cement

Chemical Composition	**%Content**		
	Ahmadi *et al.* (2007)	**Memon *et al.* (2011)**	**Sua-iam *et al.* (2013)**
Silicon Dioxide (SiO_2)	18.1	17.454	16.39
Titanium Oxide (TiO_2)	-	0.348	-
Aluminium Oxide (Al_2O_3)	5.58	4.422	3.85
Ferric Oxide (Fe_2O_3)	2.43	3.93	3.48
Manganese Oxide (MnO)	-	0.064	-
Magnesium Oxide (MgO)	2.43	2.346	0.65
Calcium oxide (CaO)	62	65.844	68.48
Sodium Oxide (Na_2O)	-	0.252	0.06
Potassium Oxide (K_2O)	-	1.117	0.52
Phosphorous Pent oxide (P_2O_5)	-	0.068	-
Sulphur Trioxide (SO_3)	3.1	3.979	4.00
LOI	4.4	-	1.70

Table 2.2 - Physical Properties of OPC

Property	**Value**		
	Ahmadi *et al.* (2007)	**Memon *et al.* (2011)**	**Sua-iam *et al.* (2013)**
Specific Gravity	3.15 g/cm^3	3.14 g/cm^3	3.2 g/cm^3
Specific Surface	3415 cm^2/g	-	610 m^2/kg

Physical and chemical Properties of RHA is shown in *Table 2.3* and *Table 2.4.*

Table 2.3 - Chemical composition limits of RHA

Constituents	**Percentage**		
	Khani *et al.* (2009)	**Habeeb *et al.* (2010)**	**Givi *et al.* (2010)**
Silica (SiO_2)	89.61	88.32	87.86
Alumina (Al_2O_3)	0.04	0.46	0.68
Iron oxide (Fe_2O_3)	0.22	0.67	0.93
Calcium Oxide (CaO)	0.91	0.67	1.30
Magnesium oxide (MgO)	0.42	0.44	0.35
Sodium oxide (Na_2O_3)	0.07	0.12	0.12
Potassium oxide (K_2O)	1.58	2.91	2.37
LOI	5.91	5.81	-

Table 2.4 - Physical Properties OF RHA

Property	**Value**		
	Khani *et al*. (2009)	**Habeeb *et al*. (2010)**	**Kishore *et al*. (2011)**
Specific Gravity	2.15	2.11	2.27
Colour	Grey	Black	Black

2.2 Properties of Study

2.2.1 Fresh concrete properties

Memon *et al.* (2008) studied the fresh concrete properties. Nine different mixes were prepared. These were subdivided into three groups: Control concrete, 5% RHA and 10% RHA. Dosage of super plasticizer was varied from 3.5% to 4.5% with an increment of 0.5%.

Slump Flow Test- Slump flow for all the mixes except 10R3.5 (10% RHA and 3.5% super plasticizer) were within the EFNARC range of SCC. Flow increased with increase in quantity of super plasticizer. Proportionally, there was decrease in the flow with increase in the quantity of RHA. The experimental readings achieved in slump flow test were from 595 to 795 mm.

L Box Test – While testing the concrete for passing ability, majority of the mixes passed through the bars very easily and without blockage. Ratio of L BOX increased with the increase in the quantity of super plasticizer. Proportionally, the ratio decreased with the increased quantity of RHA. Experimental readings achieved in L box test were from 0 to 1.

V-Funnel Test- Most of the results of V funnel test remained more towards minimum range or even lesser. This shows more filling ability but less viscous mix. With the increase in quantity of RHA, viscosity of mix started increasing.

Safiuddin *et al*. (2012) studied the fresh concrete properties of self –consolidating concrete (SCC) incorporating rice husk ash (RHA). Air entrained SCC mixtures were produced based on w/b ratios of 0.30-0.40. RHA was used substituting 0-30% of cement by weight.

Filling ability of concrete - The filling ability results of all SCC mixes were obtained with respect to slump, slump flow, inverted slump cone flow and orimet flow.

1. *Slump*

The slump varied in the range of 265-280 mm *(Table 2.5).* The slump only increased by 5mm although the deformability of concrete was significantly improved in the presence of 30% RHA. It was then suggested that the slump is not a suitable criterion to assess the filling ability of SCC.

Table 2.5: Slump of different SCC mixture (Safiuddin *et al*., 2012)

Concrete Type	**Slump (mm)**
C30RHA0	275
C30RHA15	280
C30RHA20	275
C35RHA0	270
C35RHA5	270
C35RHA10	270
C35RHA15	280
C35RHA20	275
C35RHA25	275
C35RHA30	275
C40RHA0	265
C40RHA15	270
C40RHA20	265

2. *Slump Flow*

The slump flow of SCC mixtures varied from 665 mm to 770 mm *(Table 2.6).* The range of slump flow indicates an excellent filling ability of SCC. The slump flow was significantly increased by 60 mm in the presence of 30% RHA.

Table 2.6: Slump Flow for various SCC mix (Safiuddin *et al*., 2012)

Concrete Type	Slump Flow (mm)
C30RHA0	710
C30RHA15	735
C30RHA20	770
C35RHA0	690
C35RHA5	700
C35RHA10	710
C35RHA15	720
C35RHA20	710
C35RHA25	740
C35RHA30	750
C40RHA0	665
C40RHA15	680
C40RHA20	675

3. *Orimet Test (Flow Time and Flow Spread)*

The orimet flow time of SCC mix varied from 4.8 sec to 11.5 sec *(Table 2.7).* The maximum acceptable limit for orimet flow time is 9 sec (EFNARC, 2002). The mixes having more value are more viscous than other concrete.

Table 2.7: Orimet flow of various mixes (Safiuddin *et al*., 2012)

Concrete Type	Orimet Flow	
	Flow Time (sec)	Flow Spread (sec)
C30RHA0	6.6	750
C30RHA15	9.2	770
C30RHA20	11.5	780
C35RHA0	5.7	720

C35RHA5	6.4	730
C35RHA10	7.2	740
C35RHA15	7.6	760
C35RHA20	8.8	750
C35RHA25	9.6	775
C35RHA30	10.4	795
C40RHA0	4.8	690
C40RHA15	6.8	715
C40RHA20	7.1	720

The orimet flow spread of concrete varied in the range of 690-800 mm. These results were greater than slump flow by 10-45 mm.

Passing ability of concrete- The passing ability of SCC mixtures were obtained with respect to J-ring slump, slump cone- J ring flow spread, orimet- J ring flow spread. The J-ring slump varied in the range of 255-270 mm for various SCC mixtures *(Table 2.8).* The Slump cone J-ring flow spread (slump flow in the presence of J-ring) varied in the wide range of 650-740 mm *(Table 2.8).* Reduction is observed in case of J-ring slump flow spread. The reduction in slump flow in presence of J-ring should not be greater than 50 mm to maintain a good passing ability (Ozawa *et al*., 2001).

The orimet J-ring flow spread varied in the wide range of 675-770 mm *(Table 2.8).* The presence of J-ring decreased the orimet flow spread by 15-40 mm. The inverted slump cone J-ring flow for various SCC mixes ranged from 595-710 mm *(Table 2.8).* The inverted slump cone J-ring flow spread was lower than inverted slump cone flow spread by 15-35 mm.

Table 2.8: Passing ability of different SCC mixes (Safiuddin *et al*., 2012)

Concrete Type	J-ring slump (mm)	Slump cone J-ring flow spread (mm)	Inverted slump cone J-ring flow spread (mm)	Orimet J-ring flow spread (mm)
C30RHA0	265	680	660	730

C30RHA15	270	715	700	745
C30RHA20	265	740	710	765
C35RHA0	260	670	640	690
C35RHA5	260	680	645	695
C35RHA10	260	690	655	705
C35RHA15	270	700	665	720
C35RHA20	265	695	660	715
C35RHA25	265	715	670	760
C35RHA30	265	725	675	770
C40RHA0	255	650	595	675
C40RHA15	260	660	630	700
C40RHA20	255	655	645	705

Juma *et al.* (2009) verified by using the slump flow and L-box tests, that self - compacting concrete (SCC) achieved consistency and self compact ability under its own weight, without any external vibration or compaction. Also, because of the special admixtures used, SCC has achieved a density between 2400 and 2500 kg/m^3.

Sua-iam *et al*. (2013) prepared several mixtures were prepared containing various fine aggregate replacement amounts. RHA were used to replace the river sand at levels of 0%, 10%, 20%, 40%, 60%, 80% or 100% by volume. The SCC mixtures were identified using the forms RHAx in which x is the volume percentages of river sand replaced by RHA.

Table 2.9 : Fresh properties of SCC mixes (Sua-iam *et al*., 2013)

Mix	**Slump Flow**		**J Ring Test**		**V-Funnel Time (sec)**
	Dia (cm)	**T_{50cm} (cm)**	**Dia (cm)**	**Blocking**	
Control	70	6	68	No	7
RHA10	69	6	67	No	9
RHA20	70	6	67	Minimal	11
RHA40	70	7	66	Minimal	14
RHA60	70	8	62	Extreme	N/A
RHA80	60	15	50	Extreme	N/A

RHA100	N/A	N/A	N/A	N/A	N/A

Slump Flow test -All of the mixtures exhibited satisfactory average slump flows of 70 ± 2.5 cm diameter which is an indication of good workability. The slump flow time increased with increasing RHA content. The slump flow time increased varied in the range of 6-15 sec, 8- 20 sec and 6-16 sec for SCC mixtures containing RHA.

V-Funnel test- Acceptable flow times were obtained for mixtures RHA10 and RHA20. The RHA particles absorbed water, resulting in a highly viscous mix and reducing bleeding.

J-Ring test- There was either no blocking or minimal apparent blocking in samples containing RHA. A small degree of blocking was evident in the control and in mixtures containing 10%, 20%, or 40% RHA. Extreme blocking was observed in samples containing more than 60% RHA.

2.2.2 Hardened concrete properties

2.2.2.1 Compressive strength

Ahmadi *et al.* (2007) studied the compressive strength of SSC mix containing RHA in comparison to normal mix. Six series of self compacting concrete with ordinary concrete were mixed. Two different replacement percentages of cement by RHA, 10%, and 20% with mix have no RHA and two different w/b material ratios (0.40 and 0.35), were used for both of self compacting and ordinary concrete specimens. The mixture proportions according to w/b ratio adopted and are reported in *Table 2.10* and *2.11*.

Table 2.10: Mix Design of various SCC mixes (Ahmadi *et al.*, 2007)

Mix	Gravel	Sand	Water	Cement	RHA	W/B
SCC(0%RHA)	770	970	184	460	0	0.4
SCC(10%RHA)	770	970	184	414	46	0.4
SCC(20%RHA)	770	970	184	368	92	0.4
OC(0%RHA)	1043	700	184	460	0	0.4
OC(10%RHA)	1043	700	184	414	46	0.4
OC(20%RHA)	1043	700	184	368	92	0.4

Table 2.11: Mix Design of various SCC mixes (Ahmadi *et al.*, 2007)

Mix	Gravel	Sand	Water	Cement	RHA	W/B
SCC(0%RHA)	770	970	184	460	0	0.35
SCC(10%RHA)	770	970	184	414	46	0.35
SCC(20%RHA)	770	970	184	368	92	0.35
OC(0%RHA)	1043	700	184	460	0	0.35
OC(10%RHA)	1043	700	184	414	46	0.35
OC(20%RHA)	1043	700	184	368	92	0.35

Specimen’s dimensions are shown in Table 2.12.

Table 2.12: Specimen’s Dimensions (Ahmadi *et al.*, 2007)

Type Of Test	Dimensions		
	Length (cm)	Width (cm)	Height (cm)
Compressive Strength	10	10	10

For compressive strength the specimens were test at different ages from 7 to 180 days. The results are shown in *Figure 2.1* and *Figure 2.2.* According to results SCC mixes show higher compressive strength than normal concrete. This difference is around 31% to 41% of normal concrete compressive strength. 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.

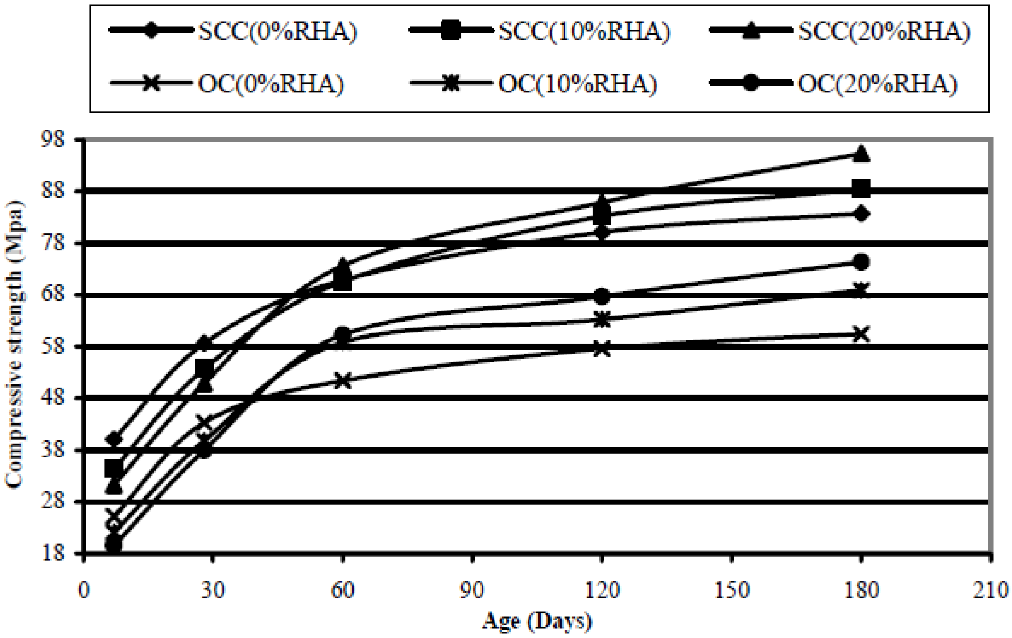


Figure 2.1: Compressive strength with w/b ratio 0.40 (Ahmadi *et al.*, 2007)

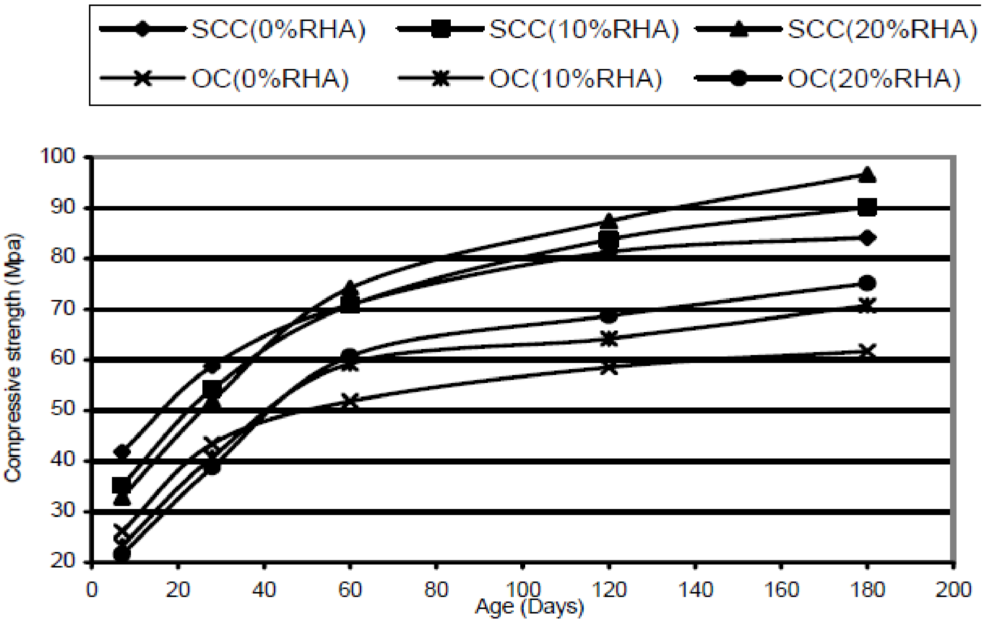


Figure 2.2: Compressive strength with w/b ratio 0.35 (Ahmadi *et al.*, 2007)

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 self-compact concrete. Moreover, by increasing the amount of replacement, water to binder ratio rises up.

Nor atan *et al*. (2011) investigates the compressive strength of self compacting concrete incorporating raw rice husk ash, individually and in combination with other types of mineral additives, as partial cement replacement.

Table 2.13: Mixture Proportions for the Control Mix, Binary Mix, Ternary Mixes and Quaternary Mixes (Nor atan *et al*., 2011)

Mix	Label	OPC	LP	FA	SF (kg/m^3)	RRHA	S	G
NM	CM	475	-	-	-	-	1047	712
BM	C/RHA	403.75	-	-	-	71.25	1027	698
TM1	C1/LP/RRHA	332.5	71.25	-	-	71.25	1023	695
TM2	C1/FA/RRHA	332.5	-	71.25	-	71.25	1007	686
TM3	C1/SF/RRHA	332.5	-	-	71.25	71.25	1012	688
QM1	C2/LP/FA/RRHA	261.25	71.25	71.25	-	71.25	1004	681
QM2	C2/LP/SF/RRHA	261.25	71.25	-	71.25	71.25	1006	683
QM3	C2/FA/SF/RRHA	261.25	-	71.25	71.25	71.25	994	676

Table 2.14: The Hardened Properties of the Control Mix (NM), Binary Mix (BM), Ternary Mixes (TM) and Quaternary Mixes (QM) (Nor atan *et al*., 2011)

Mix	Label	Age (Days)	Compressive Strength
NM	CM	7	36.5
		14	37.6
		28	37.8
		60	45.4
		90	44.7
BM	C/RRHA	7	22.7
		14	29.6
		28	39.8
		60	41.9
		90	42.5
TM1	C1/LP/RRHA	7	20.7
		14	29.4
		28	30.9
		60	38.5
		90	42.4
TM2	C1/FA/RRHA	7	24.3
		14	32.3
		28	38.9
		60	42.7
		90	43.4

TM3	C1/SF/RRHA	7	9.45
		14	38.3
		28	21.2
		60	23.6
		90	22.7
QM1	C2/LP/FA/RRHA	7	10.7
		14	13.6
		28	20.7
		60	21.4
		90	23.8
QM2	C2/LP/SF/RRHA	7	18.0
		14	26.3
		28	33.5
		60	36.9
		90	39.6
QM3	C2/FA/SF/RRHA	7	19.8
		14	25.4
		28	32.3
		60	38.3
		90	36.3

Tests carried out after 90 days reveal that the control mix (CM) obtained compressive strength values of 44.7 MPa , while the binary mix BM obtained 42.5 MPa . This shows that replacing 15% of OPC with RRHA produces slightly lower compressive strength as compared to the control mix. Similar results are also shown when 30% of OPC was replaced with LP/RRHA and FA/RRHA blends. However, 30% replacement with SF/RRHA blend produced substantially lowers compressive. Two quaternary mixes QM2 and QM3 are shown to produce comparable results with the control mix. But, quaternary mix QM1 is shown to exhibit substantially lower strength as compared with the control mix.

Saifuddin *et al.* (2010) studied the compressive strength of self consolidating high performance concrete (SCHPC). The concrete mixes were designed based on w/b ratios of 0.30, 0.35, 0.40, and 0.50, using RHA substituting 0% to 30% of cement by weight. A total air content of 6% was adopted for air entrained SCHPC’s and 2 % for non air entrained SCHPC’S. Mixes were named as per C (w/b ratio), R (replacement percentage), A (air entrained).

Highest level of later age compressive strength was achieved for C35R30A6. Conversely, the lowest level of compressive strength al all ages was obtained for C50R0A6.

The compressive strength of the concrete with and without RHA increased with a lower w/b ratio. The increase is directly proportional to the reduction in concrete porosity. In this study total porosity of concrete decreased with lower w/b ratio. With decreased porosity, microstructure of concrete is improved both in bulk paste matrix and interfacial transition zone.

The RHA increased the compressive strength of concrete at age of 7, 28 and 56 days. It is basically due to micro filling ability and pozzolanic activity of RHA.

The increased air content decreased the compressive strength of concrete. The reduction in compressive strength was about 4 MPa per 1% increase in air content. This is due to entrained air voids that increase the total void content. The increased void content decreased the load carrying capacity of concrete, producing low compressive strength.

Memon *et al.* (2010) aimed at evaluating the usage of rice husk ash as viscosity modifying agent in SCC. To calculate compressive strength nine different mixes were prepared. Three controlled mix and six mixes with different proportions of RHA. Three w/b ratios are considered i.e. 0.4, 0.38 and 0.36. Three percentages by weight of binder, super plasticizer is considered i.e. 3.5, 4 and 4.5.

Table 2.15: Compressive Strength at 7 and 28 days (Memon *et al.,* 2010)

Mix Name	**Compressive Strength**	
	7 days (MPa)	**28 days (MPa)**
CC3.5	10.5	28.4
CC4	6.8	18.3
CC4.5	1.2	8.6
5R3.5	25.2	38
5R4	21.4	37.8
5R4.5	11.9	22.2
10R3.5	22.5	36.2
10R4	36.8	41.4
10R4.5	38.3	48.5

Among the three control mixes, CC3.5 developed highest compressive strength of 10.5 and 28.4 MPa at 7 and 28 days. For control concrete and mixes with 5% RHA, the compressive strength decreased with increase in the dosage of super plasticizer. More the dosage of super plasticizer, lesser would be the strength. In the mixes with 10% RHA, the strength increased with increase in dosage due to improved workability and sufficient self compactibility. For equal dosage of super plasticizer, rice husk ash mixes showed higher compressive strength as compared to control mixes. This increase is basically due to reduced w/b ratio, dense particle packing, pore size refinement and grain size refinement.

Juma *et al.* (2009) studied that the RHA significantly increased the compressive strength of concretes at the ages of 3, 7, 14 and 28 days. The improvement of compressive strength is mostly due to the micro filling ability and pozzolanic activity of RHA and SCBA. With a smaller particle size, the RHA blended with SCBA can fill the micro-voids within the cement particles. Also, the RHA readily reacts with water and calcium hydroxide, a by-product of cement hydration and produces additional calcium silicate hydrate or CSH. The additional CSH increases the compressive strength of concrete since it is a major strength-contributing compound. Also, the additional CSH reduces the porosity of concrete by filling the capillary pores, and thus improves the microstructure of concrete in bulk paste matrix and transition zone leading to increased compressive strength. The compressive strength increases gradually with the SCC incorporated with RHA and SCBA than the one without pozzolona materials incorporated with it.

Shatat (2013) studied the effect of pozzolana on the strength of the pozzolanic cement pastes depends on number of factors such as the content, type and surface area of pozzolana and the individual characteristics of the OPC. The results of compressive strength of the blended cement pastes made from OPC-MK blends with/without rice husk ash at various curing times up to 180 days are shown in *Figure 2.3*. The compressive strength of the all pastes increases with curing time. As the hydration proceeds, more hydration products and more cementing materials are formed leading to an increase in compressive strength of cement pastes. This is mainly due to the fact that the hydration products possess a large specific volume than the unhydrated cement. Therefore, the accumulation and compaction of these hydrated products give higher strength. The compressive strength values of the hardened pastes made from OPC-MK blends including rice husk ash, increase continuously with increasing age of hydration it is clear that the best mixes are those with 5% and 10% rice husk ash (mixes R1 and R2). Thus, 5–10% addition of rice husk ash to PC-MK blends may be considered as the optimum limit. The increase in compressive strength in the presence of 5–10% rice husk ash may be both due to the pozzolanic reaction between calcium hydroxide and silica and the hydration of silica itself will be responsible for the increased compressive strength (Yu *et al.*, 1999). Up to 10% replacement of rice husk ash, the compressive strength decrease. This may be due to the fact that the quantity of RHA present in the mix is higher than the amount required to combine with the liberated lime during the hydration process thus leading to excess silica leaching out causing a deficiency in strength as it replaces part of the cementitious material but does not contribute to strength.

Table 2.16: Mix composition in wt. % of blended cements (Shatat 2013)

Symbol	OPC	MK	Rice Husk Ash
B	100	0	0
R0	75	25	0
R1	75	20	5
R2	75	15	10
R3	75	10	15
R4	75	05	20

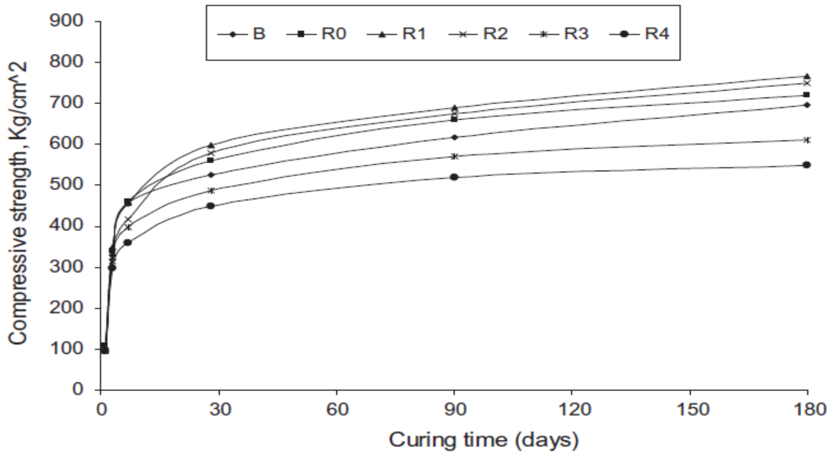


Figure 2.3: Compressive strength (kg/cm^2) of hardened specimens made from OPC and MK with/without rice husk ash as function of curing time (days) (Shatat 2013)

2.2.2.2 Flexural strength

Ahmadi *et al*. (2007) studied the flexural strength of SSC mix containing RHA in comparison to normal mix. Six series of self compacting concrete with six series of ordinary concrete were mixed. Two different replacement percentages of cement by RHA, 10%, and 20% with mix have no RHA and two different w/b material ratios (0.40 and 0.35), were used for both of self compacting and ordinary concrete specimens. The mixture proportions according to w/b ratio adopted and are reported in *Tables 2.17* and *2.18.*

Table 2.17: Mix Design for various SCC mixes (Ahmadi *et al.*, 2007)

Mix	Gravel	Sand	Water	Cement	RHA	w/b
SCC(0%RHA)	770	970	184	460	0	0.4
SCC(10%RHA)	770	970	184	414	46	0.4
SCC(20%RHA)	770	970	184	368	92	0.4
OC(0%RHA)	1043	700	184	460	0	0.4
OC(10%RHA)	1043	700	184	414	46	0.4
OC(20%RHA)	1043	700	184	368	92	0.4

Table 2.18: Mix Design for various SCC mixes (Ahmadi *et al.*, 2007)

Mix	Gravel	Sand	Water	Cement	RHA	w/b
SCC(0%RHA)	770	970	184	460	0	0.35
SCC(10%RHA)	770	970	184	414	46	0.35
SCC(20%RHA)	770	970	184	368	92	0.35
OC(0%RHA)	1043	700	184	460	0	0.35
OC(10%RHA)	1043	700	184	414	46	0.35
OC(20%RHA)	1043	700	184	368	92	0.35

All of concrete specimens were made and covered with plastic sheet and burlap for the first 24 h to prevent moisture loss. After 24 h, the specimens were de moulded and placed in the water with 22 ± 2 °C for all times of test. Specimen's dimensions are shown in *Table 2.19.*

Table 2.19: Specimen's Dimensions (Ahmadi *et al.*, 2007)

Type Of Test	Dimensions		
	Length (cm)	Width (cm)	Height (cm)
Flexural Strength	45	10	10

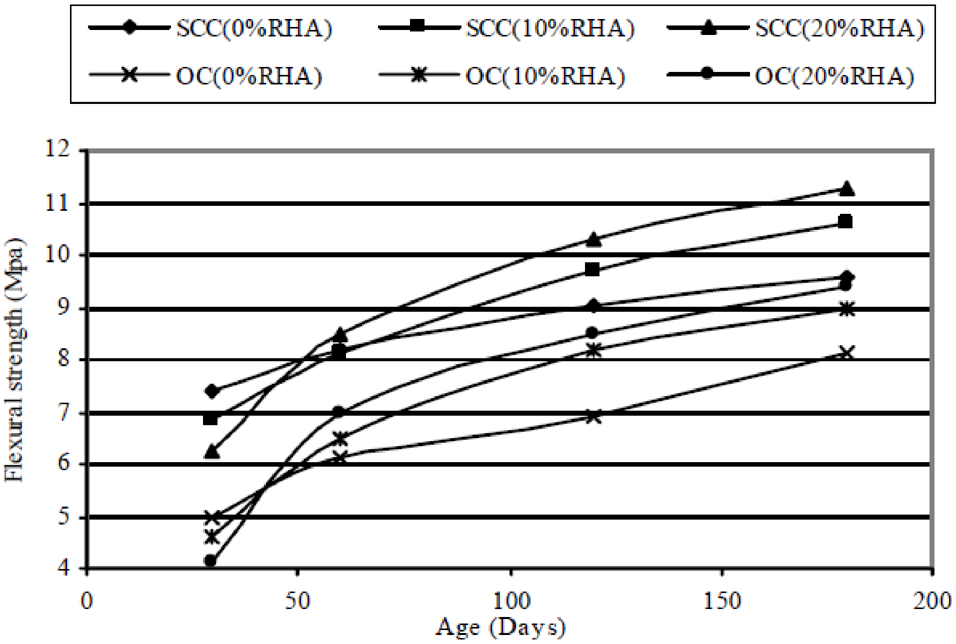


Figure 2.4: Flexural strength with w/b ratio 0.40 (Ahmadi *et al.*, 2007)

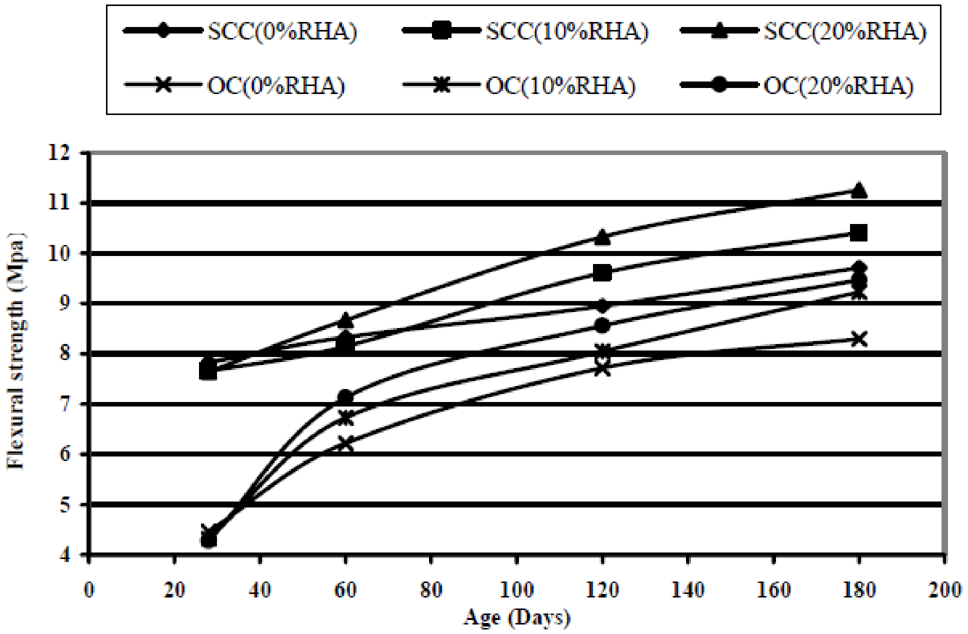


Figure 2.5: Flexural strength with w/b ratio 0.35 (Ahmadi *et al.*, 2007)

For the study of flexural strength specimens were tested at 28, 60, 120 and 180 days age, and test results have been shown in *Figure 2.4* and *2.5*

According to results, SCC mixes show the strength about 12% to 20% more than normal concrete. Also the mixes containing 20% rice husk ash have the highest flexural strength in all cases.

Nor atan *et al.* (2011) investigates the flexural strength of self compacting concrete incorporating raw rice husk ash, individually and in combination with other types of mineral additives, as partial cement replacement. The additives paired with raw rice husk ash were fine limestone powder, pulverized fuel ash and silica fumes shown in *Figure 2.6.*

Fine limestone powder

Pulverized-fuel ash

Silica fume

Raw rice husk ash

Figure 2.6: Mineral Additives used to replace Cement (OPC), Fine Limestone Powder (LP), Pulverized-Fuel Ash (FA), Silica Fume (SF) and Raw Rice Husk Ash (RRHA) (Nor atan *et al*., 2011)

Table 2.20: The Hardened Properties of the Control Mix (NM), Binary Mix (BM), Ternary Mixes (TM) and Quaternary Mixes (QM) (Nor atan *et al*., 2011)

Mix	**Label**	**Age (Days)**	**Flexural Strength**
NM	CM	7	4.5
		14	4.7
		28	5.7
		60	5.8
		90	5.7
BM	C/RRHA	7	3.2
		14	3.5
		28	4.0

		60	6.1
		90	6.5
TM1	C1/LP/RRHA	7	3.4
		14	3.8
		28	4.1
		60	5.3
		90	6.2
TM2	C1/FA/RRHA	7	2.7
		14	3.8
		28	3.7
		60	6.0
		90	5.8
TM3	C1/SF/RRHA	7	2.2
		14	5.8
		28	3.5
		60	4.0
		90	4.1
QM1	C2/LP/FA/RRHA	7	1.9
		14	2.9
		28	3.3
		60	3.7
		90	4.1
QM2	C2/LP/SF/RRHA	7	3.4
		14	4.5
		28	5.0
		60	5.7
		90	6.2
QM3	C2/FA/SF/RRHA	7	3.2
		14	3.8
		28	4.1
		60	5.2
		90	5.2

Seven SCC mixes were prepared comprising of one binary mix BM (C/RRHA), three ternary mixes TM1 (C1/LP/RRHA), TM2 (C1/FA/RRHA) and TM3 (C1/SF/RRHA) and three quaternary mixes QM1 (C2/LP/FA/RRHA), QM2 (C2/LP/SF/RRHA) and QM3 (C2/FA/SF/RRHA). One control mix (NM) was also designed using the same proportioning as the SCC mixes. Flexure strength test was carried out after 7, 14, 28, 60 and 90 days of water curing. The results are shown in Table 2.20.

2.2.2.3 Splitting tensile strength

Rahman *et al.* (2013) studied the splitting tensile strength of SCC that contained RHA as cement replacement. The percentage of RHA content in the Mix1, Mix2, Mix3 and Mix4 are 0, 20, 30 and 40 respectively. The results in *Table 2.21* shows that splitting tensile strength decreased with increase in percentage of RHA. 20% rice husk ash replacement is acceptable, as its strength is similar to the strength of controlled mix.

Table 2.21 : Splitting tensile strength (Rahman *et al.*, 2013)

Splitting Tensile Strength (MPa)			RHA Based SCC	
DAYS	**MIX 1**	**MIX 2**	**MIX 3**	**MIX 4**
28	5.1	5.1	4.3	2.8

Khadiry *et al*. (2014) aimed at producing and comparing SCC incorporating rice husk ash (RHA) and shell lime powder (SL), both locally available mineral admixtures as an additional cementing material. Split tensile strength (cylinder size: length 300 mm and diameter 150 mm), the test included for both SCC mixes for a period of 7, 14, and 28 days of curing.

Table 2.22: Splitting tensile strength for both the SCC mixes.
(Khadiry *et al.*, 2014)

Strength (MPa)	Ages (in days)	SL Based SCC	RHA Based SCC
Splitting Tensile Strength	7	1.944	1.568
	14	1.89	1.797
	28	2.51	2.53

It is clear from the *Table 2.22* and *Figure 2.7* that 28 days strength for RHA mix is higher as compared to SL. Split tensile strength of SL when compared to RHA gave a higher strength by 23.98% for 7 days of curing. For 14 days of curing, the strength of SL was 5.2% higher than that of RHA. For 28 days of curing, the strength of RHA was 0.8% higher than that of SL.

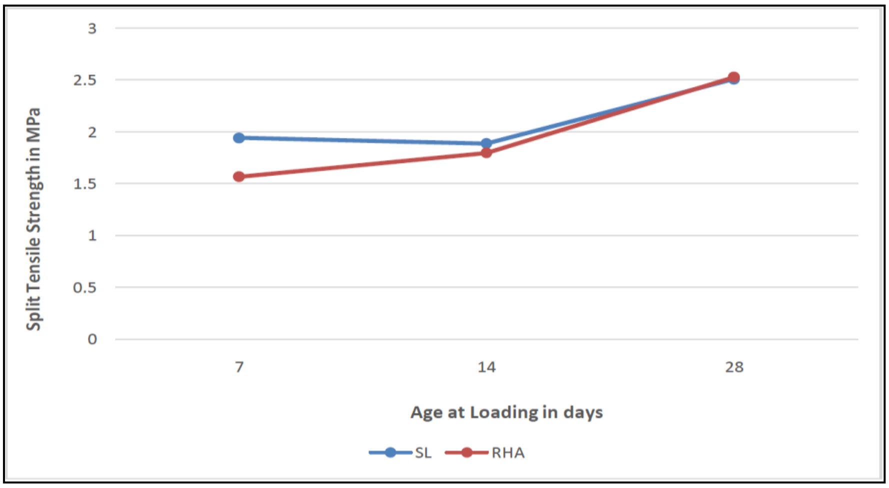


Figure 2.7: Splitting Tensile strength at various ages
(Khadiry *et al.*, 2014)

Since RHA contains silica contents and SL contains calcite contents, the silica contents react better with cement compared to that of calcite contents, as cement contains lime, which in turn consist of calcite contents. Thus, this probably explains the higher strength in RHA when compared to SL.

2.2.2.4 Modulus of Elasticity

Ahmadi *et al*. (2007) deliberate the flexural strength of SSC mix containing RHA in comparison to normal mix. Six series of self compacting concrete with six series of ordinary concrete were mixed. Two different replacement percentages of cement by RHA, 10% and 20% with mix have no RHA and two different water/cement ratios (0.40 and 0.35), were used for both of self compacting and ordinary concrete specimens. The mixture proportions according to w/b ratio adopted and are reported in *Tables 2.23* and *2.24.*

Table 2.23: Mix design for various SCC mixes (Ahmadi *et al*., 2007)

Mix	Gravel	Sand	Water	Cement	RHA	W/B
SCC(0%RHA)	770	970	184	460	0	0.4
SCC(10%RHA)	770	970	184	414	46	0.4
SCC(20%RHA)	770	970	184	368	92	0.4
OC(0%RHA)	1043	700	184	460	0	0.4
OC(10%RHA)	1043	700	184	414	46	0.4
OC(20%RHA)	1043	700	184	368	92	0.4

Table 2.24: Mix Design for various SCC mixes (Ahmadi *et al*., 2007)

Mix	Gravel	Sand	Water	Cement	RHA	W/B
SCC(0%RHA)	770	970	184	460	0	0.35
SCC(10%RHA)	770	970	184	414	46	0.35
SCC(20%RHA)	770	970	184	368	92	0.35
OC(0%RHA)	1043	700	184	460	0	0.35
OC(10%RHA)	1043	700	184	414	46	0.35
OC(20%RHA)	1043	700	184	368	92	0.35

All of concrete specimens were made and covered with plastic sheet and burlap for the first 24 hours to prevent moisture loss. After 24 h, the specimens were de moulded and placed in the water with 22 ± 2 ^{o}C for all times of test. Specimen's dimensions are shown in *Table 2.25*

Table 2.25: Specimen's Dimensions (Ahmadi *et al*., 2007)

Type Of Test	Dimensions		
MOI	Length (Cm)	Width (Cm)	Height (Cm)
	10	10	10

For the study of flexural strength specimens were tested at 28, 60, 120 and 180 days, and test results have been shown in *Figure 2.8.*

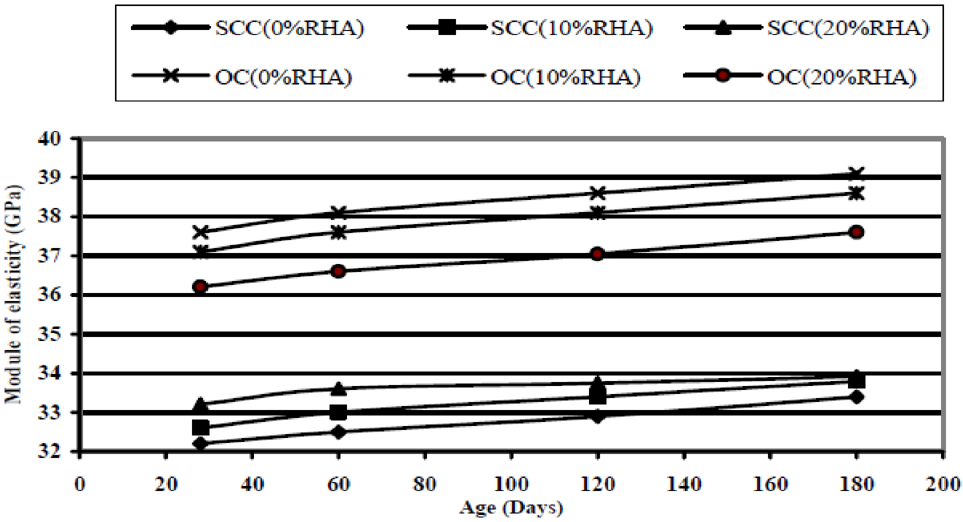


Figure 2.8: Modulus of Elasticity of various SCC mixes (Ahmadi *et al*., 2007)

According to results, by aging and hardening of concrete mixes, the module of elasticity like compressive and flexural strength increases. Normal concrete mixes show bigger module of elasticity around 9% to 17% more than of SCC ones. Also by increasing the amount of rice husk ash in the matrix, module of elasticity of all mixes reduced.

2.2.2.5 Rapid chloride permeability test

Ramasamy (2011) reported that most of the chloride ion permeability values fall in the range of very low (100-1000 coulombs) category. From the test results, it is found that as the cement replacement by rice husk ash level increases, the charge passed decreases. The incorporation of the RHA in concrete results in a finer pore structure in the hydrated cement paste especially at the aggregate and paste interface. As shown in *Figure 2.9* rapid chloride permeability decreased with the increase in age. The values obtained by mixes with the addition of SP have obtained higher values as compared to the mixes without SP. As per ASTM C1202, RHA reduced the rapid chloride penetrability of concrete from a low to very low rating from higher to lower replacement levels. The same trend was reported by Nehdi *et al.* (2003) in RHA replaced concrete. Zhang *et al.* (1996) reported that RHA concrete (10% replacement of cement) had excellent resistance to chloride ion penetration and the charge passed in coulombs was below 1000 both at 28 and 91 days.

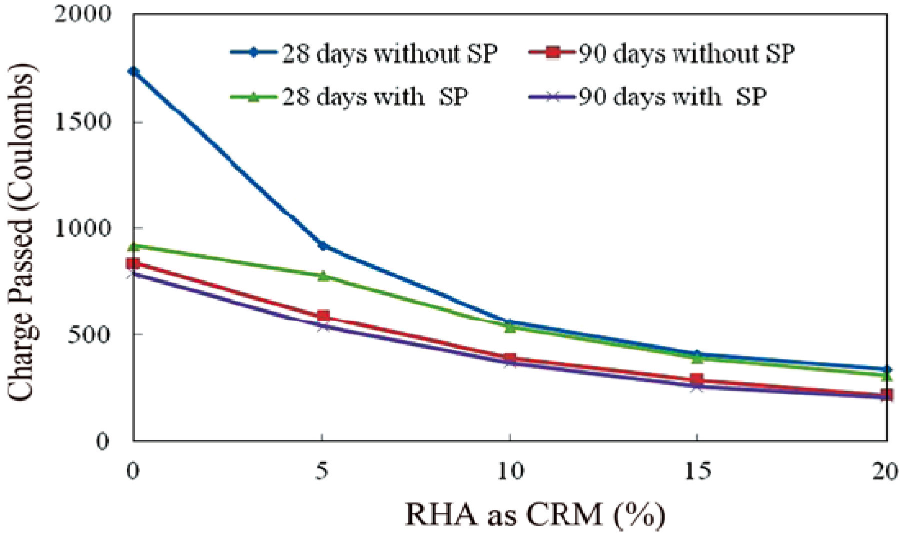


Figure 2.9: Rapid Chloride Ion Permeability in M30 Grade Concrete with and without RHA and SP (Ramasamy, 2011)

Zhang and Malhotra (1996) reported that RHA concrete (10% replacement of cement) had excellent resistance to chloride ion penetration and the charge passed in coulombs was below 1000 both at 28 and 91 days.

2.2.2.6 Porosity

Ramasamy (2011) calculated porosity test values of control concrete and different percentage of rice husk ashes in concrete after 60 days are shown in *Table 2.26*. From the results it is observed that the porosity value decreases as the percentage of replacement increases. The porosity values at 0, 5, 10, 15 and 20% rice husk ash contents 3.45, 3.90, 4.20, 4.50 and 4.70% respectively, for M30 concrete mixtures without super plasticizers. But the addition of super plasticizers showed the porosity values vary from 3.80 to 5.20% for M30 grade concrete mixtures, with SP. The small RHA particles improved the particle packing density of the concrete mixture leading to a reduced volume of larger pores.

Table 2.26: Porosity of M30 Grade Concrete Mixtures with and without RHA and SP (Ramasamy, 2011)

Sr. No.	**Mix**	**RHA Content (%)**	**SP Content By Weight of Binder (%)**	**Porosity @ 60 Days (%)**	
				Without SP	**With SP**
1	BC	0	0.40	3.45	4.20
2	BR1	5	0.40	3.90	3.90
3	BR2	10	0.80	4.20	3.80
4	BR3	15	1.40	4.50	4.40
5	BR4	20	2.80	4.70	5.20

CHAPTER: 3 EXPERIMENTAL PROGRAMMES

3.1 General

The aim of the experiment program is to compare the properties of self compacting concrete made with and without rice husk ash, used as supplementary cementing material. The basic tests carried out on cement and concrete samples are discussed in this chapter, followed by a brief description about mix design and curing procedure adopted. At the end, the various tests conducted on the specimens are discussed.

3.2 Material Used

3.2.1 Cement

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials clay predominates and in calcareous materials calcium carbonate predominates. Composition of cement and rice husk ash as per Energy Dispersive Spectroscopy analysis (EDXA; INCA x-act, Oxford Instrument, United Kingdom) is shown in *Table 3.1.*

Table 3.1: Chemical composition limits of Portland cement and Rice Husk Ash by EDX analysis

Chemical Compositions (% by mass)	Ordinary Portland Cement (Grade 43)	Rice Husk Ash
Silicon Dioxide (SiO_2)	21.24	94.0
Aluminium Oxide (Al_2O_3)	5.98	1.2
Ferrous Oxide (FeO)	4.10	0.37
Magnesium Oxide (MgO)	0.96	0.60
Calcium Oxide (CaO)	60.78	2.93
Sodium Oxide (Na_2O)	0.86	-
Potassium Oxide (K_2O)	2.20	0.50
Sulphur Trioxide (SO_3)	3.98	0.30

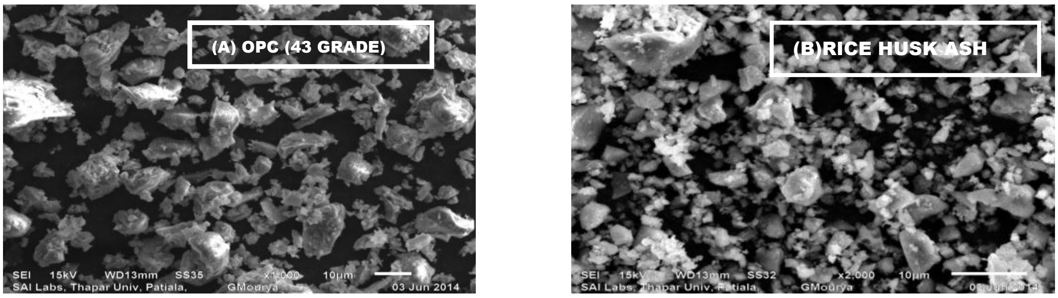


Figure 3.1: Microstructure by SEM analysis. (A) OPC (43 Grade) (B) Rice Husk Ash

Scanning Electron Micrographs at x1000 magnification for both ordinary portland cement *(Figure 3.1: A)* and rice husk ash *(Figure 3.1: B)* is shown. SEM analysis revealed that the particle shape of ordinary portland cement is irregular, whereas the rice husk ash is multilayered, micro porous and irregular.

Grade 43 Ultra Tech cement was used for casting cubes and cylinders for all concrete mixes. The cement was of uniform colour i.e. grey with a light greenish shade and was free from any hard lumps. Summary of the various tests conducted on cement are as under given below in Table 3.2

Table 3.2: Basic tests conducted on Ordinary Portland cement.

S.No.	Characteristics	Values Obtained	Standard Values IS 8112:1989
1.	**Normal Consistency (%)**	28.2	-
2.	**Initial Setting Time (min)**	128	Not be less than 30 min
3.	**Final Setting Time (min)**	192	Not be greater than 600 min
4.	**Fineness** (m^2/kg)	286.3	Not less than 225 m^2/kg
5.	**Specific Gravity**	3.51	-
COMPRESSIVE STRENGTH - CEMENT: SAND (1:3)			
1.	**3 Days**	30.2 N/mm^2	27 N/mm^2
2.	**7 Days**	41.6 N/mm^2	41 N/mm^2
3.	**28 Days**	45.2 N/mm^2	43 N/mm^2

3.2.2. Fine aggregates

The sand used for the experimental programme was locally procured and conformed to Indian Standard Specifications IS: 383 (1970). The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust. Physical properties of the fine aggregate used in the experimental work are tabulated in *Table 3.3*. The aggregates were sieved through a set of sieves to obtain sieve analysis and the same is presented in *Table 3.4*. The fine aggregates belonged to grading zone III.

Table 3.3: Physical Properties of Fine aggregates

Sr. No.	Characteristics	Value
1.	**Specific Gravity**	2.567
2.	**Bulk Density**	1.48 g/cc
3.	**Fineness Modulus**	2.465
4.	**Water Absorption**	1.914%
5.	**Grading Zone (Based on percentage passing 0.60 mm)**	III

Table 3.4: Gradation of fine aggregates

Sieve Size (mm)	Material Retained	Percentage Retained	Percentage Passing	Cumulative Percentage
80	0	0.00	100.00	0.00
40	0	0.00	100.00	0.00
20	0	0.00	100.00	0.00
10	0	0.00	100.00	0.00
4.75	5	0.50	99.50	0.50
2.36	59	5.90	93.60	6.40
1.18	136	13.60	80.00	20.00
600	243	24.30	55.70	44.30
300	415	41.50	14.20	85.80
150	122	12.20	2.00	98.00
PAN	20	2.00		
SUM	1000		SUM	255.00
Total weight taken = 1000 g Fineness Modulus of sand = 2.56				

3.2.3 Coarse aggregates

The material which is retained on IS sieve no. 4.75 is termed as a coarse aggregate as per IS: 383 (1970).The crushed stone is generally used as coarse aggregates. The nature of work decides the maximum size of the coarse aggregates. Locally available coarse aggregates having the maximum size of 10 mm was used in our work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 2386 (1963) (Part 3). The results of various tests conducted on coarse aggregates are given in *Table 3.5* and *Table 3.6* shows the sieve analysis results.

Table 3.5: Physical Properties of Coarse Aggregates (10 mm)

Sr. No.	Characteristic	Value
1.	**Type**	Crushed
2.	**Specific Gravity**	2.66
3.	**Total Water Absorption**	0.56%
4.	**Fineness Modulus**	6.83

Table 3.6: Gradation of 10 mm aggregates

Sr No.	Sieve Size (Mm)	Material Retained	Percentage Retained	Percentage Passing	Cumulative Percentage Retained
1	80	0.00	0.00	100.00	0.00
2	40	0.00	0.00	100.00	0.00
3	20	0.005	0.249	99.73	0.249
4	10	0.485	24.23	75.5	24.479
5	4.75	1.25	62.46	13.04	86.93
6	2.36	0.00	0.00	0.00	100
7	1.18	0.00	0.00	0.00	100
8	600	0.00	0.00	0.00	100
9	300	0.00	0.00	0.00	100
10	150	0.00	0.00	0.00	100
11	PAN	0.261	13.04	-	-
				SUM	111.658

Total weight taken = 3kg

Fineness modulus of coarse aggregates = $\frac{\Sigma C+500}{100} = \frac{500+111.658}{100}$

= 6.11

3.2.4 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting.

3.2.5 Supplementary cement materials

3.2.5.1. Rice husk ash

Rice Husk Ash is obtained from Mullanpur district Ludhiana. The chemical composition of RHA as per EDX analysis is shown in *Table 3.1. Plate 3.1* shows the rice husk ash used in the present study.

Plate 3.1: Rice husk ash used in the study

3.2.6 Admixture

Conplast SP430 complies with IS: 9103 (1979), BS: 5075 (Part 3) and ASTM-C-494 Type ‘F’ as a high range water reducing admixture. Conplast SP430 is based on Sulphonated Naphthalene Polymers and is supplied as brown liquid instantly dispersible in water and specially formulated to give high water reduction up to 25% without loss of workability, Specific gravity 1.22 to 1.225 at 30 °C.

3.3. Mixture Proportioning

Table 3.7: Mix proportions of various SCC mixes

Mixture ID	**Cement (kg/m^3)**	**RHA (kg/m^3)**	**RHA (%)**	**Sand (kg/m^3)**	**CA (kg/m^3)**	**Water (kg/m^3)**	**w/b**	**SP (kg/m^3)**	**SP (%)**
0RHA	550	0	0	910	590	225.5	0.41	5.5	1
10RHA	495	55	10	910	590	225.5	0.41	5.5	1
15RHA	467.5	82.5	15	910	590	225.5	0.41	5.5	1
20RHA	440	110	20	910	590	225.5	0.41	5.5	1

Where,

0RHA = Control Mix with 0% RHA as cement replacement.

10RHA = Self-compacting Concrete with 10 % RHA as cement replacement.

15RHA = Self-compacting Concrete with 15 % RHA as cement replacement.

20RHA = Self-compacting Concrete with 20 % RHA as cement replacement.

RHA = Rice Husk Ash

CA = Coarse aggregates

SP = Super plasticizer.

3.4 Casting and Curing

For casting, the entire test specimen were cleaned and oiled properly. These were securely tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage of slurry. Careful procedure was adopted in the batching, mixing and casting operations. The coarse aggregates and fine aggregates were weighed first with an accuracy of 0.5 g. The concrete mixture was prepared by hand mixing on a non-absorbing platform. On the non-absorbing platform, the coarse and fine aggregates were mixed thoroughly. Then water was added carefully so that no water was lost during mixing. To this mixture, the cement was added. These were mixed to uniform colour. Then water was added carefully so that no water was lost during mixing. For each mix 24 samples were prepared, which consists of 9 cubes (150x150x150 mm) for 7, 28 and 56 days compressive strength and 9 cylinders (300x150 mm) for split tensile strength at 7, 28 and 56 days and 6 cylinders (200x100 mm) for RCPT at 7 and 28 days.

3.5 Tests Conducted

3.5.1. Fresh concrete tests (EFNARC, 2002)

SCC differs from conventional concrete in that its fresh properties are vital in determining whether or not it can be placed satisfactorily. The various aspects of workability which control its Filling ability, its Passing ability and its Segregation resistance all need to be carefully controlled to ensure that its ability to be placed remains acceptable. A concrete mix can only be classified as Self-compacting Concrete if the requirements for all three characteristics are fulfilled.

- **Filling Ability**: Ability of to fill a formwork completely under its own weight.
- **Passing Ability**: Ability to overcome obstacles under its own weight without hindrance. Obstacles are e.g. reinforcement and small openings etc.
- **Segregation Resistance**: Homogeneous composition of concrete during and after the process of transport and placing.

It is important to appreciate that none of the test methods for SCC has yet been standardised, and the tests described are not yet perfected or definitive. The methods presented here are descriptions rather than fully detailed procedures. They are mainly ad-hoc methods, which have been devised specifically for SCC.

3.5.1.1 Slump flow test

The slump flow test is done to assess the horizontal flow of concrete in the absence of obstruction. It is most commonly used test and gives good assessment of filling ability. It can be used at sites. The test also indicates the resistance to segregation. The typical slump cone used is shown in *Figure 3.2.*

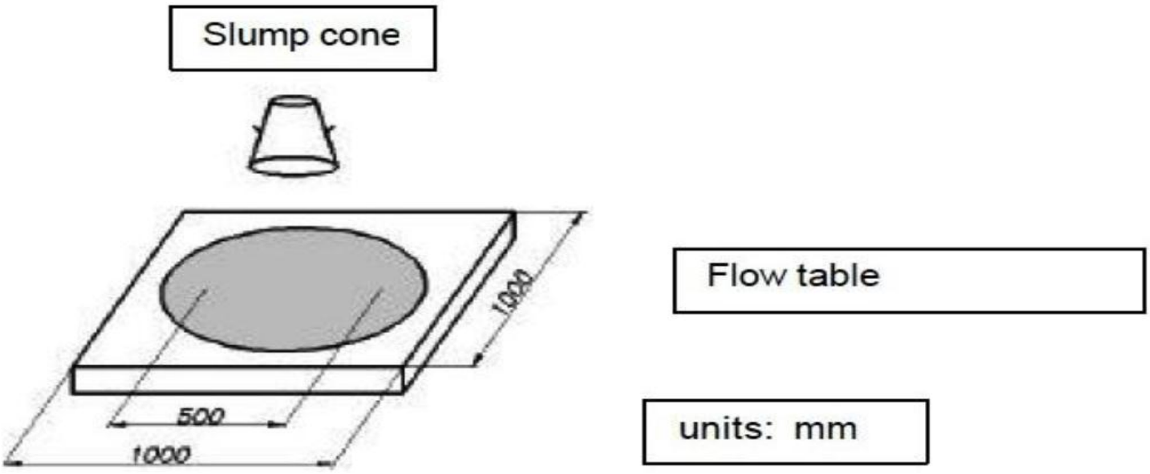


Figure 3.2: Schematic diagram for Slump flow test (EFNARC, 2002)

Equipments

- The usual slump cone having base diameter of 200 mm, top diameter 100 mm and height 300 mm is used.
- A stiff base plate square in shape having at least 700 mm side. Concentric circles are marked around the centre point where the slump cone is placed. A firm circle is drawn at 500 mm diameter.
- A trowel
- Scoop
- Measuring tape
- Stop watch

Procedure

- About 6 L of concrete is needed for the test.
- Base plate is kept at a levelled ground surface. Keep the slump cone centrally on the base plate.
- Fill the cone with the scoop. Tamping is not at all required in this case. Simply strike of the concrete level with the trowel. Remove the surplus concrete lying on base plate.
- Raise the cone firmly and allow the concrete to flow freely.
- Measure the final diameter of concrete in two perpendicular directions and calculate the average of two diameters.
- This gives the slump flow in mm.
- Note that there is no water or cement paste or mortar without aggregates at the edges of the spread concrete.

Interpretation

The higher the flow value, greater is its ability to fill the formwork under its own weight. A value of at least 650 mm is required for SCC. In case if the aggregates are collected at centre and mortar at sides, segregation is observed.

3.5.1.2 T_{50} Slump flow test

Basic procedure for the test is same as in case of slump flow test. When the slump cone is lifted start the stop watch and find the time taken for the concrete to reach 500 mm mark. This time is called T_{50} time. This is an indication of rate of spread of concrete. A lower time indicates greater flow ability. It is suggested that T_{50} time may be 2 to 5 sec. The research suggested that a time of 3-7 sec is acceptable for civil engineering applications, and 2-5 sec for housing applications.

3.5.1.3 V-Funnel test

This test was developed in Japan and was used by Ozawa for the first time in 2001. The equipment consists of a V-shaped funnel as shown in *Figure 3.3*

This test is basically used to determine filling ability (flow ability) of concrete. The maximum size of aggregate used is 20 mm size. The funnel is filled with about 12 L of concrete. Time taken for the concrete to flow down is recorded.

For T_5min test the funnel is filled with concrete and left for 5 min to settle down. If the concrete shows segregation then the flow time will increase significantly.

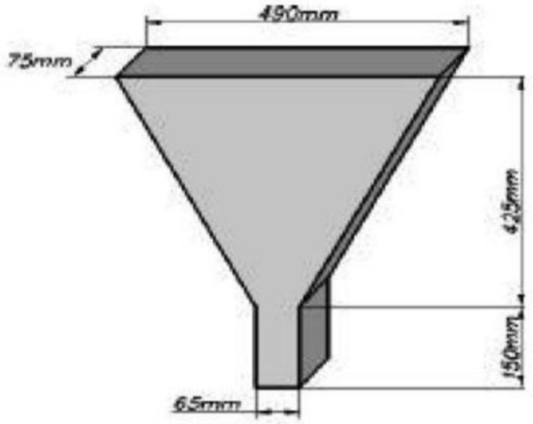


Figure 3.3: Typical V- Funnel (EFNARC, 2002)

Equipments

- V-funnel
- Bucket – 12 L capacity
- Trowel
- Scoop
- Stopwatch

Procedure

- About 12 L of concrete is needed to perform the test, sampled normally.
- Set the V-funnel on firm ground.
- Moisten the inside surfaces of the funnel.
- Keep the trap door open to allow any surplus water to drain.
- Close the trap door and place a bucket underneath.
- Fill the apparatus completely with concrete without compacting or tamping, simply strike off the concrete level with the top with the trowel.
- Open within 10 sec after filling the trap door and allow the concrete to flow out under gravity.

- Start the stopwatch when the trap door is opened, and record the time for the discharge to complete (the flow time). This is taken to be when light is seen from above through the funnel.
- The whole test has to be performed within 5 min.

Interpretation

This test measures the ease of flow of the concrete; shorter flow times indicate greater flow ability. For SCC a flow time of 8-12 sec is considered appropriate. The inverted cone shape restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking. After 5 min of settling, segregation of concrete will show a less continuous flow with an increase in flow time.

3.5.1.4 L- Box test

This test is based on a Japanese design for underwater concrete. The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. *Figure 3.4* shows the apparatus regarding L- box test.

The apparatus consist of rectangular section box in the shape of an 'L', with a vertical and horizontal section, separated by a movable gate, in front of which vertical length of reinforcement bar are fitted. The vertical section is filled with concrete, and then the gate 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 is expressed as a proportion of that remaining in the vertical section. It indicates the slope of the concrete when at rest. This is an indication 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 200 mm and 400 mm 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.

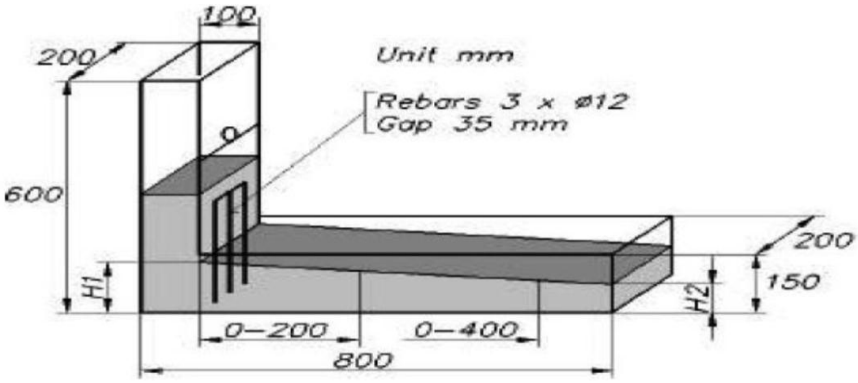


Figure 3.4: Schematic diagram for L- Box (EFNARC, 2002)

Equipments

- L box of a still non absorbing material
- Trowel
- Scoop
- Stopwatch

Procedure

- About 14 L of concrete is needed to perform the test, sampled normally.
- Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.
- Moisten the inside surfaces of the apparatus, remove any surplus water.
- Fill the vertical section of the apparatus with the concrete sample.
- Leave it to stand for 1 min.
- Lift the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously, start the stopwatch and record the times taken for the concrete to reach the 200 and 400 mm marks.
- When the concrete stops flowing, the distances H1 and H2 are measured.

Interpretation

If the concrete flows as freely as water, at rest it will be horizontal therefore H_2/H_1 will be equal to 1. Therefore nearer the test value, the blocking ratio is to unity, better the flow of concrete. Minimum acceptable value is 0.8. T_{20} and T_{40} time can give some indication of ease of flow. No suitable values have been suggested in this case. Obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

3.5.1.5 U-Box test

This test was developed in Japan. This test was basically used to measure the filling ability of self compacting concrete. This test was also called as “box- shaped” test. The apparatus shown in *Figure 3.5* consists of a vessel that is divided by a middle wall into two compartments i.e. R_1 and R_2

An opening with a sliding gate is fitted between two chambers. 13 mm nominal diameter bars are installed at the gates with c/c distance of 50 mm. Clear spacing between the bars was 35 mm. Left hand chamber was filled with 20 L of concrete. The gate is then lifted and concrete is allowed to pass to another chamber. Heights of concrete in both chambers are measured.

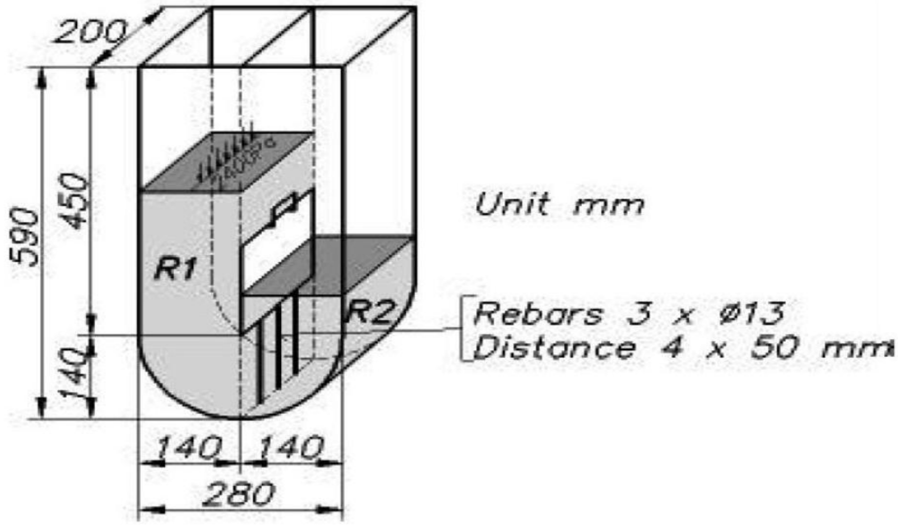


Figure 3.5: Schematic diagram for typical U-Box (EFNARC, 2002)

Equipment

- U box of a stiff non absorbing material
- Trowel
- Scoop
- Stopwatch

Procedure

- About 20 L of concrete is needed to perform the test, sampled normally.
- Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.
- Moisten the inside surfaces of the apparatus, remove any surplus water.

- Fill the one compartment of the apparatus with the concrete sample.
- Leave it to stand for 1 min.
- Lift the sliding gate and allow the concrete to flow out into the other compartment.
- After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and calculate the mean (H1). Measure also the height in the other compartment (H2)
- Calculate H1 - H2, the filling height.
- The whole test has to be performed within 5 min.

Interpretation

If concrete flows as freely as water, H2-H1=0. Nearer the test value, the filling height is to zero, better the flow and passing ability of concrete. The acceptable value of filling height is 30 mm maximum.

3.5.2 Hardened Concrete Properties

3.5.2.1 Compressive strength IS: 516 (1959)

*Objective***:** Determine the compressive strength of concrete specimen.

Apparatus: Testing Machine: The testing machine should be of sufficient capacity for the tests and capable of applying the load at the specified rate. The permissible error shall not be greater than 2% of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the plates shall be fitted with a ball seating in the form the portion of the sphere, the centre of which coincides with the central point of the face of the platen. The other compression plates shall be plain rigid bearing block. The bearing faces of both plates shall be at least as larger as, and it should preferably be larger than the normal size of the specimen to which the load is applied. The bearing surface of the plates, when new, shall not depart from a plane by more than 0.01 mm at any point, and they shall be maintained with a permissible variation limit of 0.02 mm, the movable portion of the spherical seated compression plates shall be held on the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

Age at test: Tests shall be made at recognised ages of the test specimens, the most usual being 7 and 28 days. The ages shall be calculated from the time of the addition of water of the dry ingredients.

Number of Specimens: At least three specimens, preferably from different batches, shall be made for testing at each selected age.

Procedure: Specimens stored in water shall be tested immediately on removal from the water and while they are still in the wet condition. Surface water and grit shall be wiped off the specimens and any projecting find removed specimens when received dry shall be kept in water for 24 h before they are taken for testing. The dimensions of the specimens to the nearest 0.2 mm and their weight shall be noted before testing. Placing the specimen in the testing machine the bearing surface of the testing machine shall be wiped clean and any loose sand or other material removed from the surface of the specimen, which are to be in contact with the compression platens. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and steel platen of the testing machine. As the spherically seated block is brought to bear on the specimen, the movable portion shall be rotated gently by hand so that uniform seating may be obtained. The load shall be applied without shock and increased continuously at a rate of approximately 140 kg/cm^2/min. until the resistance of the specimen to the increasing load breaks down and any unusual features in the type of failure shall be noted.

Calculation: the measured compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen during the test by the cross sectional area, calculated from the mean dimensions of the section and shall be expressed to the nearest kg/cm^2. Average of three values shall be taken as the representative of the batch provided the individual variation is not more than ±15 percent of the average. Otherwise repeat tests shall be made. A correction factor according to the height/diameter ratio of specimen after capping shall be obtained from the curve shown in Figure.1 of IS: 516-1959. The product of this correction factor and the measured compressive strength shall be known as the corrected compressive strength this being the equivalent strength of a cylinder having a height/diameter ratio of two. The equivalent cube strength of the concrete shall be determined by multiplying the corrected cylinder by 5/4.

Plate 3.2: Compression testing machine used for study.

3.5.2.2 Split tensile strength IS: 5816 (1999)

Apparatus: Compression Testing Machine

Materials

150 x 300 mm moist cured concrete cylinders

Procedure

1) Draw diametric lines on each end of the specimen so that they are in the same axial plane.

2) Centre one of the plywood strips along the centre of the lower bearing block.

3) Place the specimen on the plywood strip and align so that the lines marked on the ends are vertical and centred over the plywood strip.

4) Place the second plywood strip and the bearing bar so that they are lengthwise on the cylinder, centred on the previously marked lines on the ends.

5) Apply the load continuously until failure occurs The load shall be applied without shock and increased continuously at a nominal rate within the range 1.2 N/ (mm^2/min) to 2.4 N/ (mm^2/ min).

6) Record the maximum load at failure.

7) Calculate the split tensile strength as follows:

$$f_{st} = \frac{2P}{\pi l d}$$

Where, f_{st} is the measured split tensile strength, P is the maximum load at failure in N, and l and d are the length and diameter of the cylindrical specimen, respectively, in mm.

Report

The following information shall be included in the report on each specimen:

a) Date of test

b) Identification mark, shape and size of the specimen in mm

c) Age of specimen at date of test when known

d) Curing history

e) Weight of specimen in N

f) Type of fracture and the appearance of concrete on the fractured face if these are unusual

g) Splitting tensile strength to the nearest 0.05 N/mm’ on the lower side

h) Estimate of the proportion of coarse aggregate fractured during test.

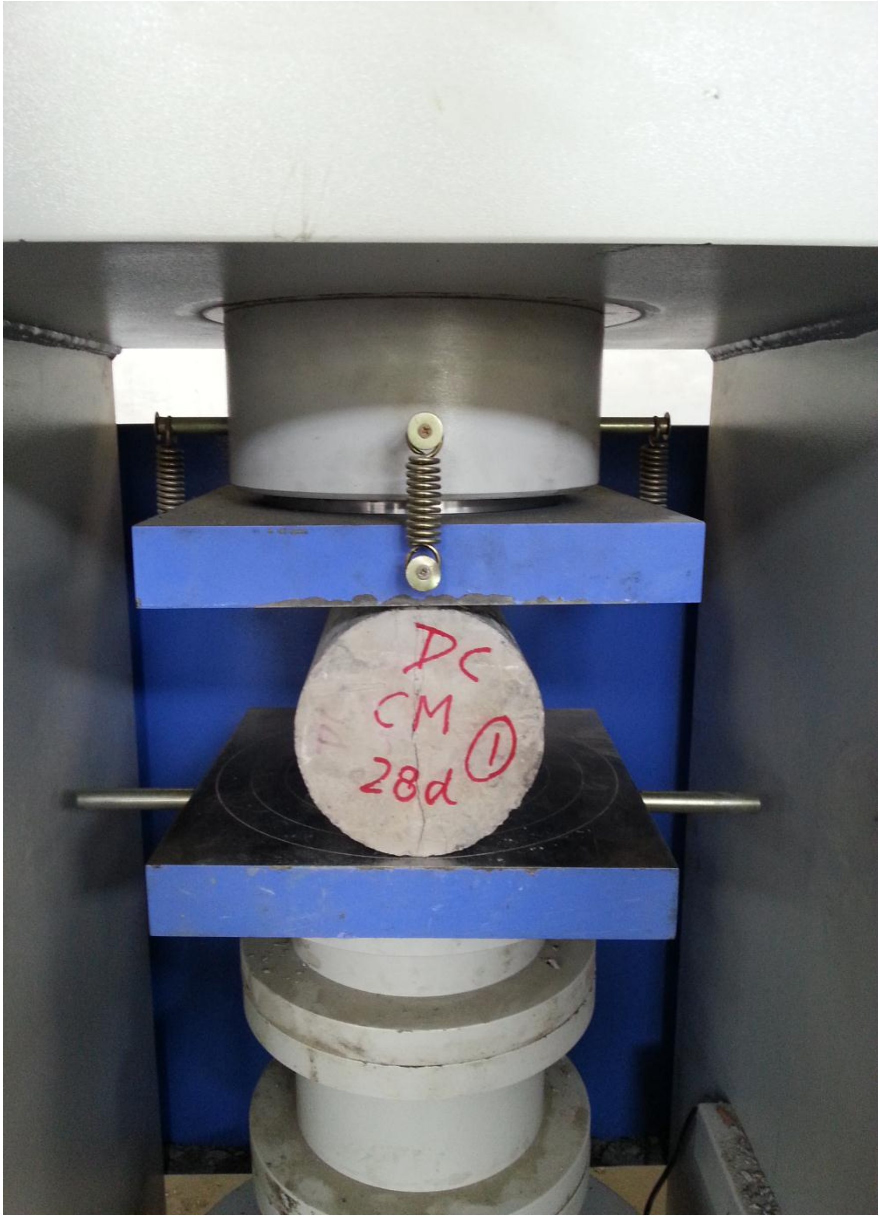


Plate 3.3: Split tensile strength machine used in this study

3.5.2.3 Rapid chloride permeability test (RCPT) ASTM C 1202 (2010)

The RCPT was originally developed for the Federal Highway Administration (FHWA) by the Portland Cement Association (Whiting, 1981) to provide a rapid test method that correlated well with ponding tests, such as AASHTO T 259. Ponding tests are considered to be the best method of determining the chloride permeability of concrete, but they take 90 days or more to complete, making them impractical for project quality assurance testing. Two very similar standards (AASHTO T 277 and ASTM C 1202) describe the rapid chloride permeability test. The tests are performed using 2 in. (51 mm) long, 3.75 in. (95 mm) diameter cylindrical specimens cut from cores obtained with a diamond-dressed coring After the curved surface of a test specimen is coated with epoxy, the specimen is vacuum saturated with water Rapid Chloride Permeability Tests and then soaked for 18 h. As shown in *Figure 3.6.* and *Figure 3.7*. The specimen is then placed in the testing apparatus where one end of the specimen is exposed to a solution containing 3% sodium chloride (NaCl) and the other end is exposed to a solution containing 0.3 N sodium hydroxide (NaOH). To increase the rate of chloride penetration into the specimen thus speeding up the test, a constant 60 V potential is applied across the specimen. The current across the specimen is measured at least every 30 min during the 6 h test. In theory, as the chlorides penetrate deeper into the concrete, the pore solution becomes more conductive and the current readings increase. In concretes with high conductivity values, however, these effects are small relative to changes in conductivity due to temperature rise. To reduce the effects of heating and resultant changes in conductivity over the 6 h period of the test, it’s been suggested that earlier values be adjusted to obtain an equivalent 6 h coulomb value.. The total charge passing through the specimen (in coulombs) is found by calculating the total area under the plot of time versus current. Therefore, higher coulomb values at the completion of the test indicate higher permeability.

Plate 3.4: Vacuum Desiccators bowl

Figure 3.6: Rapid chloride permeability test set up (ASTM C 1202).

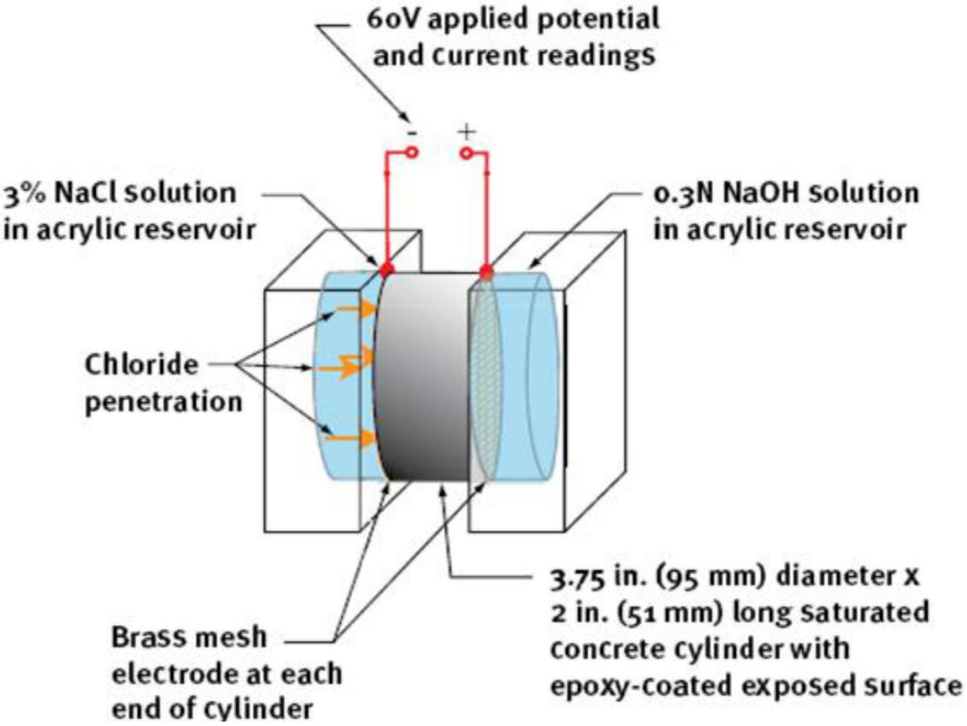


Figure 3.7: Schematic representation of rapid chloride permeability test setup

The rapid chloride permeability test does not, however, directly measure the depth or rate of chloride penetration. This makes it difficult to directly correlate results from the test with a desired service life and has led to a significant amount of debate about the proper use and applicability of the test. It should also be noted that, in quality control and acceptance testing applications, ASTM C 1202 (2010) recommends the use of the qualitative terms shown in the right hand column of *Table 3.8*, rather than the numerical results of the test.

Table 3.8: Chloride ion penetrability based on charge passed (ASTM 1202-2010)

Charge Passed (coulombs)	Chloride Ion Penetrability
>4000	HIGH
2000-4000	MODERATE
1000-2000	LOW
100-1000	VERY LOW
<100	NEGLIGIBLE

3.5.2.4 Porosity ASTM C 642 (2006)

Aim – Determination of density, percentage absorption and percentage voids in hardened concrete.

Significance and Use

This test method is useful in developing the data required for conversions between mass and volume for concrete. It can be used to determine conformance with specifications for concrete and to show differences from place to place within a mass of concrete.

Apparatus

- Balance, sensitive to 0.025 % of the mass of the specimen.
- Container, suitable for immersing the specimen and suitable wire for suspending the specimen in water.

Test Specimen

The sample shall consist of several individual portions of concrete, each to be tested separately. The individual portions may be pieces of cylinders, cores, or beams of any desired shape or size, except that the volume of each portion shall be not less than 350 cm^3 (or for normal weight concrete, approximately 800 g); and each portion shall be free from observable cracks, fissures, or shattered edges.

Procedure

1. Oven-Dry Mass—Determine the mass of the portions, and dry in an oven at a temperature of 100 to 110 °C for not less than 24 h. After removing each specimen from the oven, allow it to cool in dry air (preferably in desiccators) to a temperature of 20 to 25 °C and determine the mass. If the specimen was comparatively dry when its mass was first determined, and the second mass closely agrees with the first, consider it dry. If the specimen was wet when its mass was first determined, place it in the oven for a second drying treatment of 24 h and again determine the mass. If the third value checks the second, consider the specimen dry. In case of any doubt, re dry the specimen for 24 h periods until check values of mass are obtained. If the difference between values obtained from two successive values of mass exceeds 0.5 % of the lesser value, return the specimens to the oven for an additional 24 h drying period, and repeat the procedure until the difference between any two successive values is less than 0.5 % of the lowest value obtained. Designate this last value A.

2. Saturated Mass after Immersion - Immerse the specimen, after final drying, cooling, and determination of mass, in water at approximately 21 ^{o}C for not less than 48 h and until two successive values of mass of the surface-dried sample at intervals of 24 h show an increase in mass of less than 0.5 % of the larger value. Surface-dry the specimen by removing surface moisture with a towel, and determine the mass. Designate the final surface-dry mass after immersion B.

3 Saturated Mass after Boiling - Place the specimen, processed as described in 5.2, in a suitable receptacle, covered with tap water, and boil for 5 h. allow it to cool by natural loss of heat for not less than 14 h to a final temperature of 20 to 25 °C. Remove the surface moisture with a towel and determine the mass of the specimen. Designate the soaked, boiled, surface-dried mass C.

4 Immersed Apparent Mass - Suspend the specimen, after immersion and boiling, by a wire and determine the apparent mass in water. Designate this apparent mass D.

Plate 3.5 Samples boiled in curing tank at maintained temperature.

Calculation

By using the values for mass determined in accordance with the procedures described in, make the following calculations:

1. Absorption after immersion, % = [[B-A]]/A]*100

2. Absorption after immersion and boiling, % = [[C-A]/A]*100

3. Bulk density, dry = [A/[C-D]] ρ =g_1

3. Bulk density after immersion = [B/[C-D]] ρ

4. Bulk density after immersion and boiling = [C/[C-D]] ρ

5. Apparent density = [A/[A-D]] ρ = g_2

6. Volume of permeable pore space or voids = $[(g_2-g_1) / g_2]*100$

OR

$[(C-A)/(C-D)]*100$

Where:

A = mass of oven-dried sample in air, g

B = mass of surface-dry sample in air after immersion, g

C = mass of surface-dry sample in air after immersion and boiling, g

D = apparent mass of sample in water after immersion and boiling, g

g_1 = bulk density, dry, mg/m^3 and

g_2 = apparent density, mg/m^3

r = density of water = 1 mg/m^3 = 1 g/cm^3.

3.5.2.5 X-ray diffraction (XRD)

For X-Ray Diffraction (XRD) the samples which were already casted and cured for 28 days are crushed and pulverised to an average particle size of 10 microns. After that this crushed sample was mounted on the glass fibre filter using tubular aerosol suspension chamber (TASC). After placing the sample in the chamber the mass absorption coefficient of the sample was determined by X-Ray transmission (Xpert pro, Panalytical, United states). The XRD pattern was observed by scanning the sample from 10-80 degrees, 2 theta and having Cu radiation and graphite monochromatic with a current of 30 KV and a voltage of 40 MV by using a vertical X-ray diffract meter.

3.5.2.6 Scanning electron microscopy (SEM)

Scanning Electron Microscopy (6510-LV, JOEL, Japan) is conducted to study the micro-structure properties of the samples. The samples which were already casted and cured for 28 days are used for the test. This test is used to identify the changes which had occurred inside the micro-structure and also the formation and deformation of the phases.

CHAPTER: 4 RESULTS AND DISCUSSIONS

4.1 General

In this chapter the parameters studied on control and concrete made with replacement of cement with rice husk ash in self compacting concrete are discussed. The parameters such as Compressive strength, Tensile strength, Rapid chloride permeability test, Porosity, X-Ray diffraction (XRD), Scanning electron microscope (SEM) are discussed and comparison between various mixes are discussed.

Rice Husk Ash

Replacement of rice husk ash with cement on concrete is basically discussed in this article. Reactivity of rice husk ash is basically due to the high amorphous silica content and also due to large surface area governed by porous structure of particles. This makes rice husk ash a very reactive pozzolanic material. In chemical reaction of Portland cement in concrete, there is release of calcium hydroxide. Silica present in rice husk ash reacts with this calcium hydroxide to form additional binder material called as calcium silicate hydrate (C-S-H) similar to the C-S-H produced by Portland cement. It works as additional binder that gives RHA concrete its improved properties. Mechanism of rice husk ash in concrete can be studied basically under three roles:

- *Matrix Densification and Pore size Refinement*: The presence of filler like rice husk ash in the Portland cement concrete mixes causes reduction in volume of large pores. RHA acts as filler due to its fineness. It fits into the spaces between grains in same way like cement grains fill the spaces between fine aggregates grains and sand fills the spaces between particles of coarse aggregates.

- *Reaction with free-lime (From hydration of cement):* CH crystals present in Portland cement pastes are a source of weakness. Cracks can easily propagate through or within these crystals without any significant resistance. This affects the strength, durability and other properties of concrete. Rice husk ash which is siliceous material reacts with CH results in reduction in CH content in addition to forming strength contributing cementitious products which in other words can be termed as ‘‘Pozzolanic Reaction’’.

- *Cement paste–aggregate interfacial refinement*: In concrete the transition zone between the aggregate particles and cement paste plays a significant role in the cement-aggregate bond. Rice husk ash addition influences the thickness of transition phase in mortars and the degree of the orientation of the CH crystals in it. The thickness compared with mortar containing only ordinary Portland cement decreases. Hence mechanical properties and durability is improved because of the enhancement in interfacial or bond strength. Mechanism behind is not only connected to chemical formation of C–S–H (i.e. pozzolanic reaction) at interface, but also to the microstructure modification (i.e. CH) orientation, porosity and transition zone thickness) as well.

4.1.1 Fresh concrete properties

In order to study the effect on fresh concrete properties when rice husk ash is added to the concrete as cement replacement, the SCC containing different proportions of rice husk ash were tested for Slump flow, V-funnel, L-box and U-box.

Various mixes have been designed and tested for fresh concrete properties. SP content varied from 0.8-1.5% and w/b ratio was varied from 0.35-0.45. Optimum results was obtained by the mix with 1% SP and 0.41 w/b ratio.

The results of fresh properties of all self compacting rice husk ash concrete are included in Table: 4.1. The table shows the properties such as Slump flow, V-funnel flow time, L-box, U-box. In terms of Slump flow, all SCC's exhibited satisfactory slump flow in the range of 550-800 mm, which is an indication of good deformability.

Table 4.1: Fresh concrete properties for mixes with and without Rice Husk Ash

Mixture ID	Slump Flow (mm)	V-Funnel Time (sec)	U-Box (H1-H2)	L-Box (H2/H1)
0RHA	730	6	5	1
10RHA	700	8	18	0.9
15RHA	670	11	25	0.8
20RHA	600	13	30	BLOCKING

As per EFNARC, time ranging from 6-12 sec is considered adequate for a SCC. The V-funnel flow times were in the range of 4-13 sec. Test results of this investigation indicated that all SCC mixes meet the requirement of allowable flow time. Maximum size of aggregate was kept as 12 mm in order to avoid blocking effect in L-box. The gap between re-bars of L-box test is 35 mm. The L-box ratio H2/H1 for the mixes was above 0.8 i.e. as per EFNARC range. The U-box difference in height of concrete in two compartments was in range of 5-40 mm. All the fresh properties of concrete values were in good agreement to that of values given by European guidelines. *Plate 4.1, Plate 4.2, Plate 4.3* shows various fresh concrete properties test results.

Plate 4.1: Achieved Slump Flow by Slump Flow Test

Plate 4.2: L-box test for fresh concrete properties

Plate 4.3: V-funnel test for fresh concrete properties

4.2.2 Compressive strength

In order to study the effect on compressive strength when rice husk ash is added to the self compacting concrete, as cement replacement, the cube containing different proportions of rice husk ash was prepared and cured for 7 days, 28 days and 56 days. The test was conducted on ASTM capacity 3000 KN. From the results as mentioned in *Table 4.2*, it is concluded that 56 days strength is higher than 7d and 28d strength. This is basically due to continuous hydration of cement with concrete.

Table 4.2: Compressive strength test results for various SCC mixes

MIX	7 Days		28 Days		56 Days	
	Comp Strength (N/mm^2)	Avg. Comp. Strength (N/mm^2)	Comp. Strength (N/mm^2)	Avg. Comp. Strength (N/mm^2)	Comp. Strength (N/mm^2)	Avg. Comp. Strength (N/mm^2)
0RHA	29.0	29.0	35.4	36.7	39.4	39.6
	29.0		37.6		39.8	
	29.0		37.2		39.8	
10RHA	34.0	32.6	41.4	41.2	46.6	46.4
	32.6		39.8		45.8	
	31.4		42.5		46.9	
15RHA	36.8	36.2	49.4	48.8	54.0	53.7
	34.7		48.2		52.9	
	37.2		48.8		54.3	
20RHA	30.6	30.4	40.4	40.2	53.0	53.0
	31.2		39.8		53.8	
	29.4		40.4		52.2	

Effect of percentage of replacement of rice husk ash on compressive strength of self compacting concrete

The compressive strength test results of SCC mixes are given in *Table 4.2* and shown in *Figure 4.1* and *Figure 4.2*. The w/c ratio was kept constant 0.41 for all mixes. With increase in RHA content from (10-20%), SCC mixes develop compressive strength between 29.0 and 32.6 MPa for 7 days, 36.7 and 41.2 MPa for 28 days and 39.6 and 46.4 MPa for 56 days. The compressive strength increases with increase in percentage of rice husk ash up to 15% replacement, after that strength starts decreasing. The highest level of later age compressive strength was achieved for 15RHA which contained 15% RHA. Conversely, the lowest compressive strength was achieved by Controlled mix (CM) at all ages as shown in *Figure 4.1*. It has also been observed from *Figure 4.2* that compressive strength increases with increase in age.

The increase of about 25% strength at 7 days, 33% strength at 28 days and 36% strength at 56 days were observed with increase of Rice husk ash content from CM to 15RHA. The results obtained are comparable to the results given by Safiuddin *et al*. (2010)

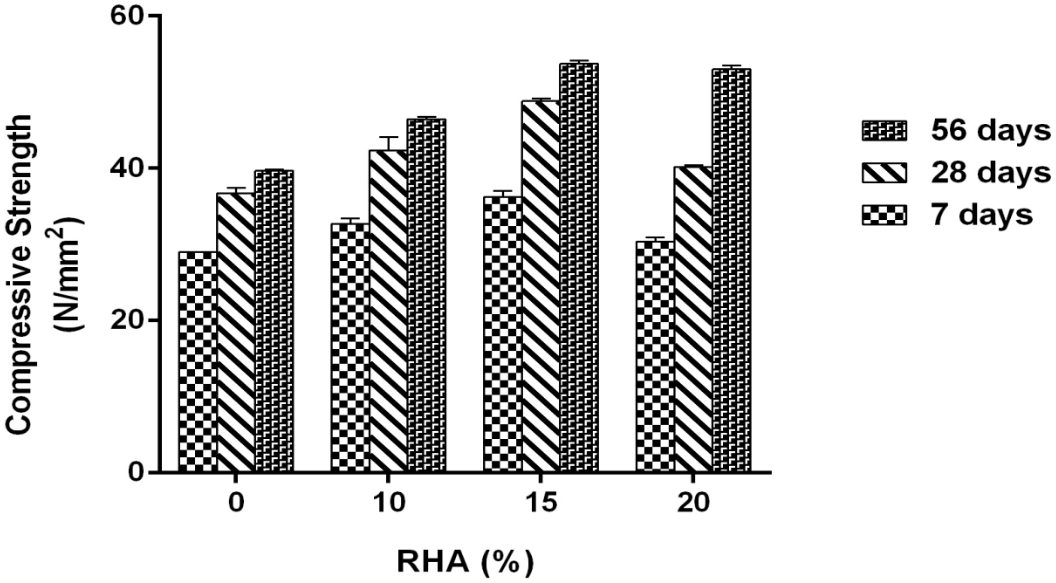


Figure 4.1: Compressive strength of SCC mixes at various ages.

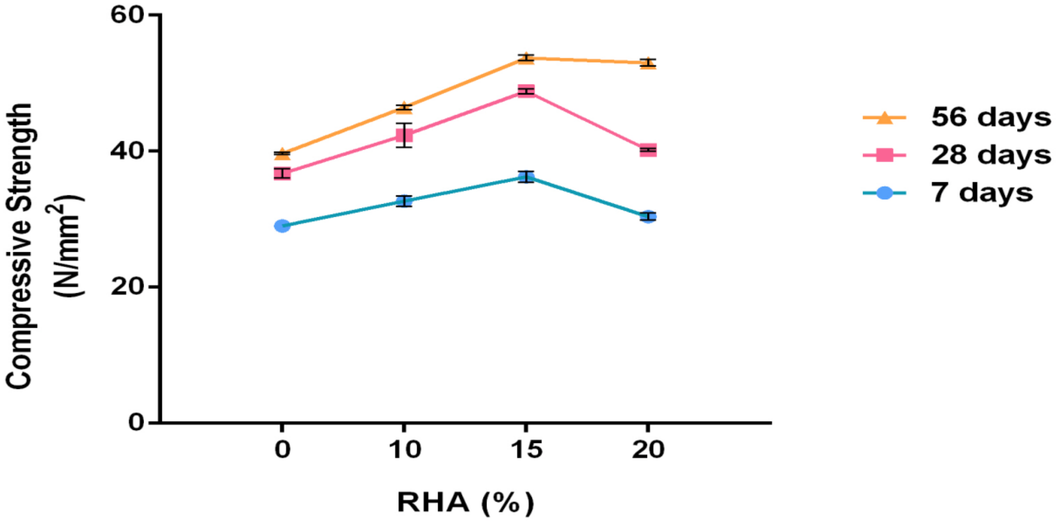


Figure 4.2: Variation of Compressive strength of SCC mixes with respect to age.

The improvement of compressive strength is mostly due to micro filling ability and pozzolanic activity of RHA. With a smaller particle size, the RHA can fill the micro voids within the cement particles. Also the RHA is highly reactive, it reacts with calcium hydroxide (a by product of cement hydration) and produces additional C-S-H. The additional C-S-H reduces the porosity of concrete by filling the capillary pores, and thus improving the microstructure of concrete in bulk paste matrix and transition zone leading to an increased compressive strength.

Decrease in compressive strength is observed at 20RHA. In this case, the amount of silica available in the hydrated blended cement matrix is probably too high and the amount of the produced C-H is most likely insufficient to react with all the available silica and as a result of that, some amount of silica was left without any chemical reaction.

4.2.3 Splitting tensile strength

Split tensile strength studies were carried out at the age of 7 days, 28 days and 56 days.

Table 4.3: Split Tensile strength results of SCC mixes with and without Rice Husk Ash

Mix	7 Days		28 Days		56 Days	
	STS (N/mm^2)	ASTS (N/mm^2)	STS (N/mm^2)	ASTS (N/mm^2)	STS (N/mm^2)	ASTS (N/mm^2)
0RHA	2.0	2.0	2.6	2.5	2.8	2.8
	2.1		2.5		3.0	
	2.0		2.5		2.7	
10RHA	2.3	2.4	3.8	3.6	3.7	3.8
	2.4		3.4		3.9	
	2.7		3.6		3.9	
15RHA	2.8	2.8	3.5	3.7	4.0	4.0
	2.9		3.8		4.1	
	2.8		3.8		3.9	
20RHA	2.4		3.2		3.3	
	2.3		2.8		3.6	

	2.3	2.3	3.0	3.0	3.1	3.3

The highest strength is obtained by the mix 15RHA at all ages. As per results given in Table 4.2 the split tensile strength increased with increase in percentage of RHA up to 15% replacement by RHA. As shown in *Figure 4.3* and *Figure 4.4* splitting tensile strength increased with increase in age. There is decrease in strength for mix 20RHA, but the values are still higher than control mix at all ages. With increase in RHA content from (10-20%) SCC mixes develop splitting tensile strength between 2.0 and 2.8 MPa for 7 days, 2.5 and 3.7 MPa for 28 days and 2.8 and 4.0 MPa for 56 days. Above results are comparable to results calculated by Khadiry *et al.* (2014) and Rahman *et al.* (2013).

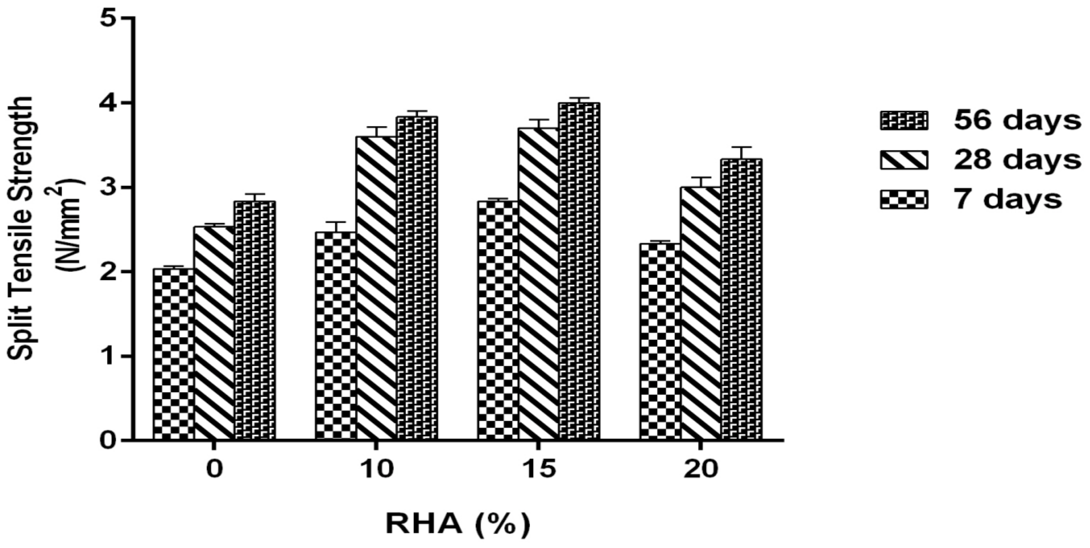


Figure 4.3: Split tensile strength of SCC mixes at various ages

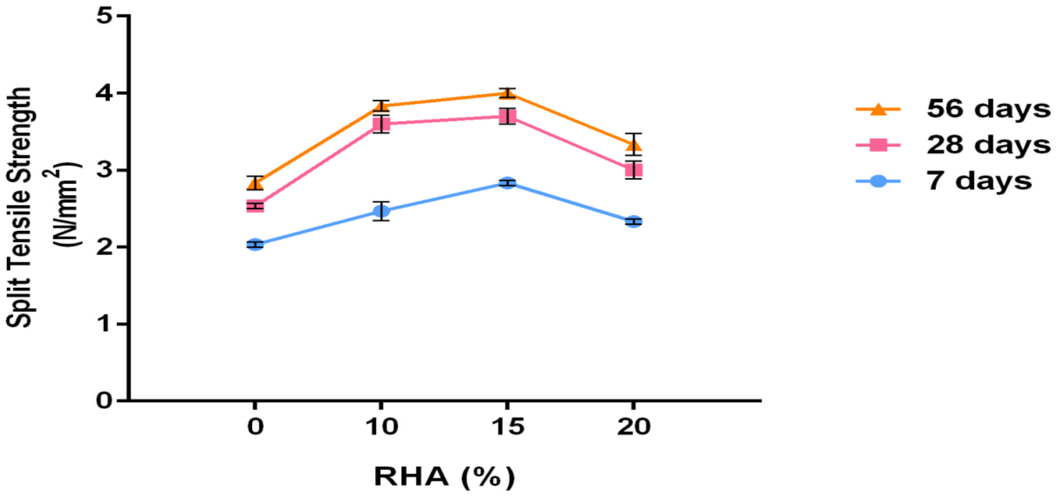


Figure 4.4: Variation of Split tensile strength of SCC mixes with respect to age

4.2.4 Rapid chloride permeability test

The 28 days test results for the resistance to penetration of chloride ions into concrete, measured in terms of the electric charge passed through the specimens in coulombs for different SCC mixes with and without rice husk ash are give in *Table 4.4*. The measurement concerns the chloride ions that come into concrete and those flowing through the samples. The current passed through the concrete mixtures are 2837, 1969, 912 and 1173 coulombs respectively at 28 days for the replacement level of 0, 10, 15 and 20%. From the results it was found that as the replacement of rice husk ash level increases, the charge passed decreased, except in case of 20RHA in which charge passed increased , but is still less than the CM *(Figure 4.5).* The permeability class ranged from moderate for CM to very low for 15RHA. The other mixes also show low permeability. The results can be compared to the results given by Ramasamy (2011) and Zhang and Malhotra (1996).

This is mainly due to the fact that incorporation of the RHA in concrete results in finer pore structure in the hydrated cement paste especially at the aggregate and paste interface.

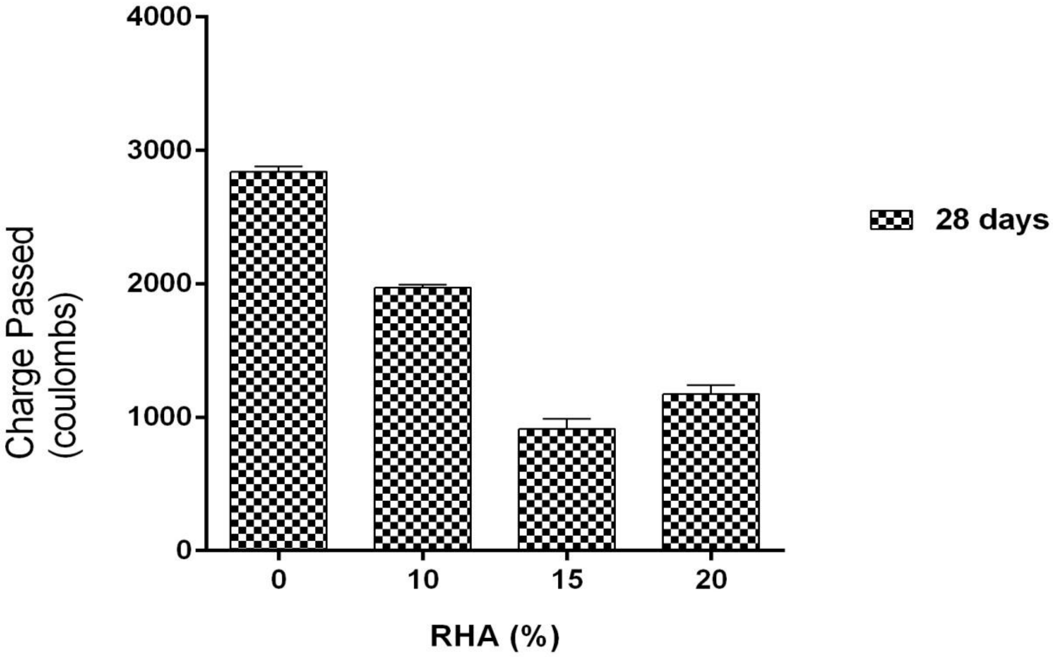


Figure 4.5: Charge passed of rapid chloride penetration test (RCPT)

Table 4.4: Charge passed and rating for SCC mixes

Mix	28 DAYS		
	Charge Passed In Coulombs (C)	**Avg. Charge Passed (C)**	**Chloride Ion Permeability**
0RHA	2907	2837	Moderate
	2762		
	2843		
10RHA	2016	1969	Low
	1945		
	1948		
15RHA	769	912	Very Low
	945		
	1023		
20RHA	1061	1173	Low
	1295		
	1163		

4.2.5 Porosity

The porosity is the significant factor as it affects directly the durability of the SCC. The results of porosity of SCC concrete mixes are given in *Table 4.5* and shown in *Figure 4.6.*

The results indicate that the porosity decreased with increase in curing time. The main reason behind this is due to the additional or increased rate of hydration and/or pozzolanic reactions. There is more formation of C-S-H gel as a product of pozzolanic reaction between calcium hydroxide and silica. This gel fills the voids and increases the density of concrete.

Lowest porosity is achieved by mix 15RHA. 20RHA mix shows increase in porosity, but it is still less than the CM.

As shown in *Figure 4.7*, the porosity decreased with increase in age. This is basically due to large formation of C-S-H gel, dense structure is formed so porosity decreased. Results are comparable to results given by Ramasamy (2013).

Table 4.5: Porosity values for various SCC mixes

Mix (%)	**Porosity (%)**	**Avg. Porosity (%)**	**Porosity (%)**	**Avg. Porosity (%)**
	7 Days		**28 Days**	
0 RHA	11.6	12.4	10.3	10.9
	13.1		10.8	
	12.4		11.6	
10 RHA	10.6	10.8	9.88	10.3
	11.1		10.6	
	10.7		10.3	
15 RHA	9.9	9.9	9.3	9.0
	10.0		9.0	
	10.0		8.8	
20 RHA	11.5	11.0	10.3	9.8
	10.8		9.5	
	10.8		9.7	

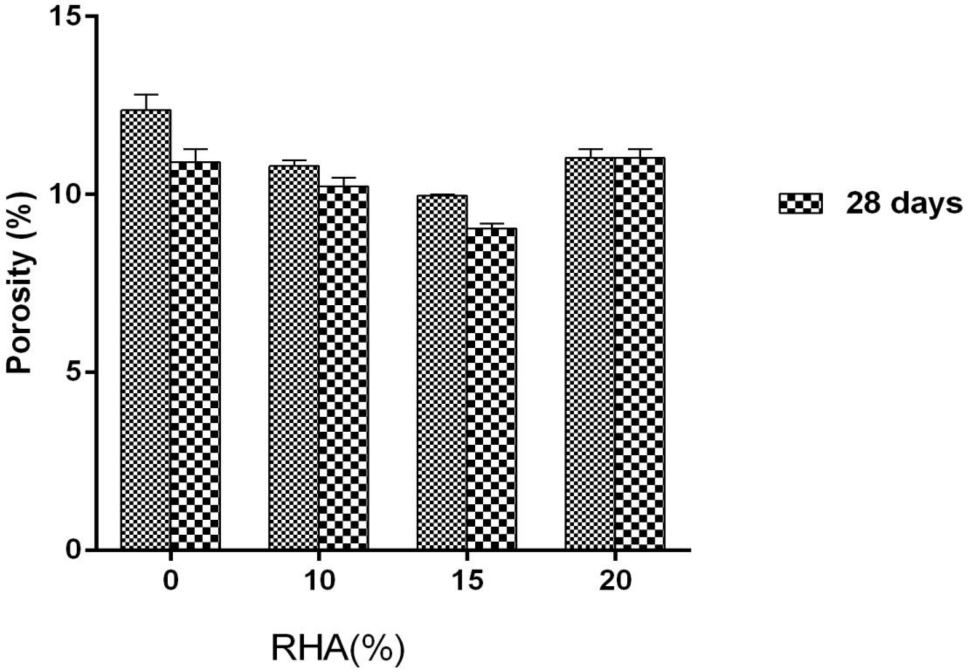


Figure 4.6: Porosity of various SCC mixes with respect to age

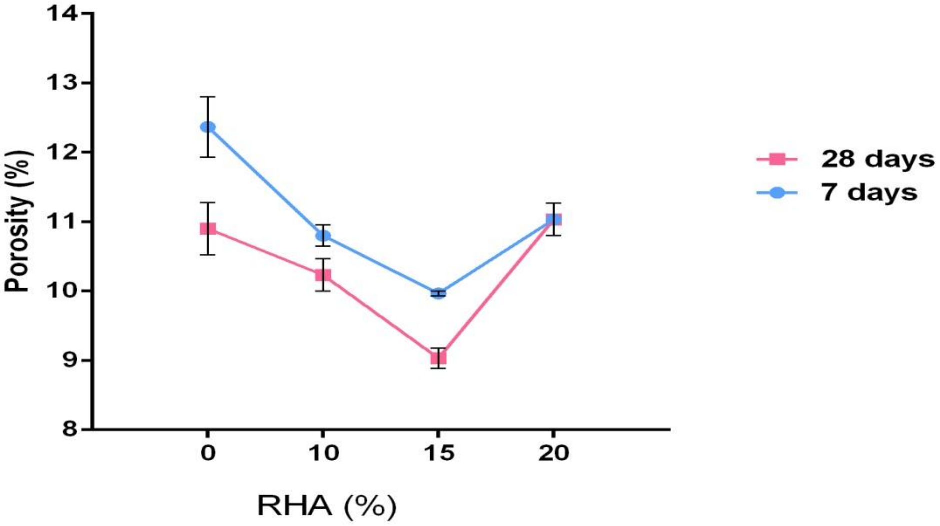


Figure 4.7: Porosity variation of various SCC mixes

4.2.6 SEM analysis

SEM images of unblended SCC (100% OPC), 10% RHA, 15% RHA and 20% RHA is shown in *Figure 4.8*.

It is well known that, C-S-H gel is the major phase present. The factors that influence the mechanical behaviour of C-S-H phases are: size and shape of the particles, distribution of particles, particle concentration, particle orientation, topology of the mixture, composition of the dispersed/continuous phases and the pore structure.

According to literature it was assumed that bright and dark matter in the images represents C-S-H gel. Small irregular dense medium dark particles are assumed as RHA. The basic structure of concrete in all the mixes is same as the mix designed is kept constant in all samples expect change in RHA content. *Figure 4.8* shows micrographs of various mixes. It shows clear spread of C-S-H gel at various stages.

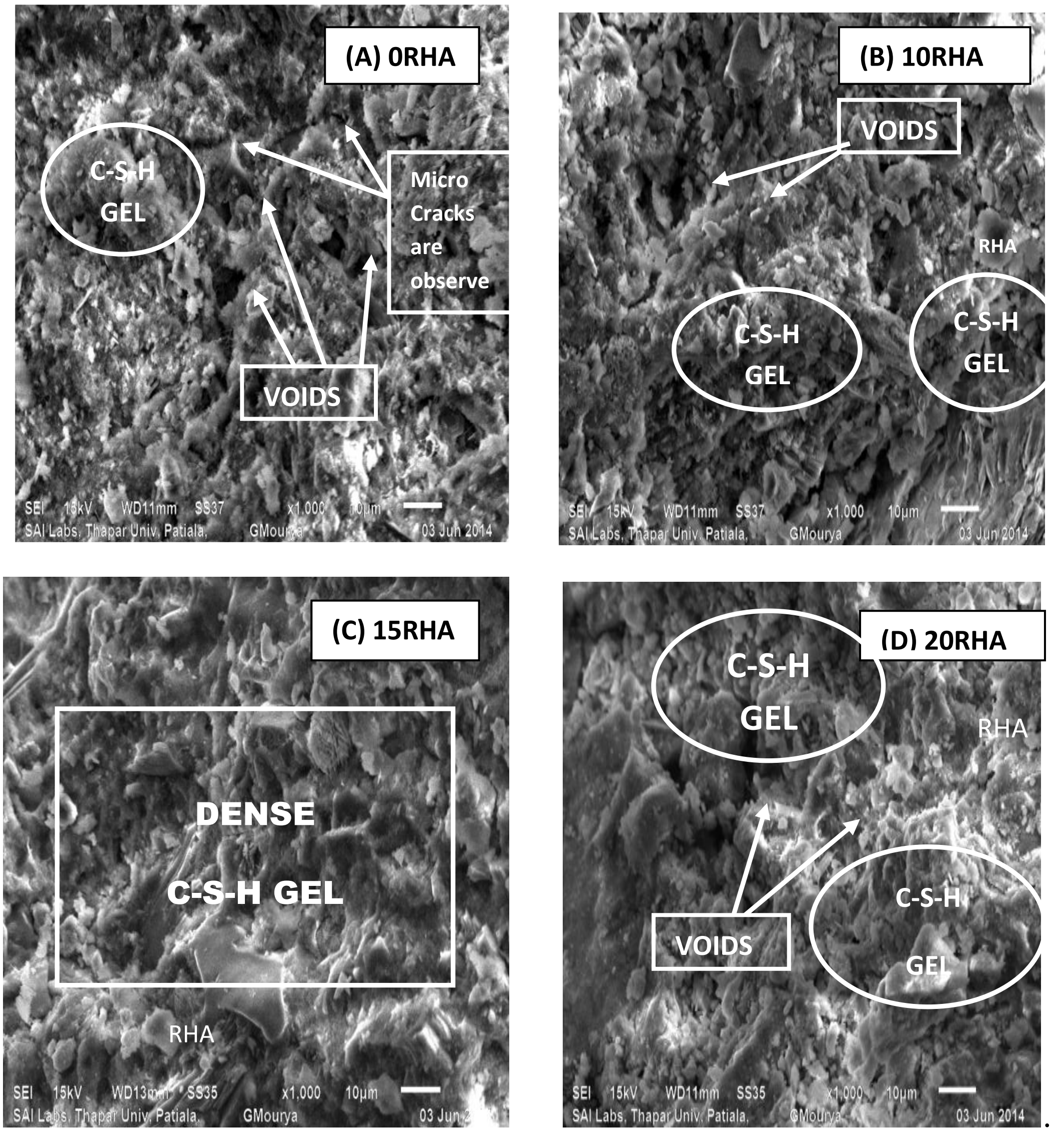


Figure 4.8: Micrographs of various mixes (A) 0RHA (B) 10RHA (C) 15RHA (D) 20RHA

Figure 4.8 A shows mix with 0% RHA replacement. It is observed that in unblended concrete mix consist of irregular particles with micro pores and cracking is also observed. This may be the main reason for poor performance in relation to strength and durability as compared to blended concrete. C-S-H gel is spread over the entire micrograph as the C-S-H gel gets spread over the aggregates that act as binders.

Figure 4.8 B shows mix with 10% RHA replacement. It is observed that micro pores have decreased due to hydration progress. C-S-H gel is more widely spread in this case giving a uniform dense structure than unblended concrete. This may be the reason for slight increase in strength and durability properties as compared to unblended concrete.

Figure 4.8 C shows mix with 15% RHA replacement. It is observed that pore structure have highly improved to a greater extent. No pores or cracking is observed in this case. C-S-H gel is fully spread over the micrograph leading to highly uniform and dense structure. This may be the reason for the maximum strength and improved durability properties as compared to all other mixes. The fibrous C-S-H formation acts as a thick impermeable membrane for the ingress of chloride ions into concrete. This makes the concrete more resistant to aggressive environment as observed from RCPT values.

Figure 4.8 D shows mix with 20% RHA replacement. It is observed that mix have started crumbling as the amount of RHA is increased. C-S-H gel is not seen at all the places. Crumbling of mix may be the reason for reduced strength and degraded durability properties of this mix.

4.2.7 X-ray diffraction

XRD analysis was conducted to analyze the components of concrete mixes and the material used and the results are shown in Figure 4.12(a) to Figure 4.12(f). The X-Ray Diffraction pattern and analysis of the concrete mixes i.e. reference mix, and RHA mixes was carried out at age of 28 days. One of the major problems encountered in the qualitative and quantitative analysis of cement is that there was strong overlapping of major diffraction peaks of all the main phases of cement components. X-ray diffraction (XRD) analysis of concrete samples with or without rice husk ash shows peaks of quartz (Q), calcium silicate hydrate (CSH), and ettringite (e) phases.

The XRD patterns of OPC and RHA that were used for this study are shown in Figure 4.9(a) and Figure 4.9(b). XRD analysis showed that the RHA was mainly in amorphous silica form. Very less crystalline silica form is observed in the form of cristobalite. From XRD analysis of OPC it was observed that the main products were C_2S and C_3S. Alite (C_3S) is the major mineral component (>50%) found in cement and upon hydration forms calcium silicate hydrate or calcium silicate which hardens the cement slurry and is responsible for initial (1–3 days) and final strengths, (Jumate et al., 2011). The second major component found in cement is C_2S or Belite or Larnite (Ca_2SiO_4). Larnite reacts with water to form calcium silicate hydrate or calcium silicate and portlandite, and responsible for the development of late strength.

Jumate et al. (2011) studied that hydration and hydrolysis reaction of C_2S and C_3S mineral components produce calcium silicate hydrate (also known as Tobermorite) gels and later the solid phase develops crystals during curing period leading to strengthening of the cement-concrete mixes.

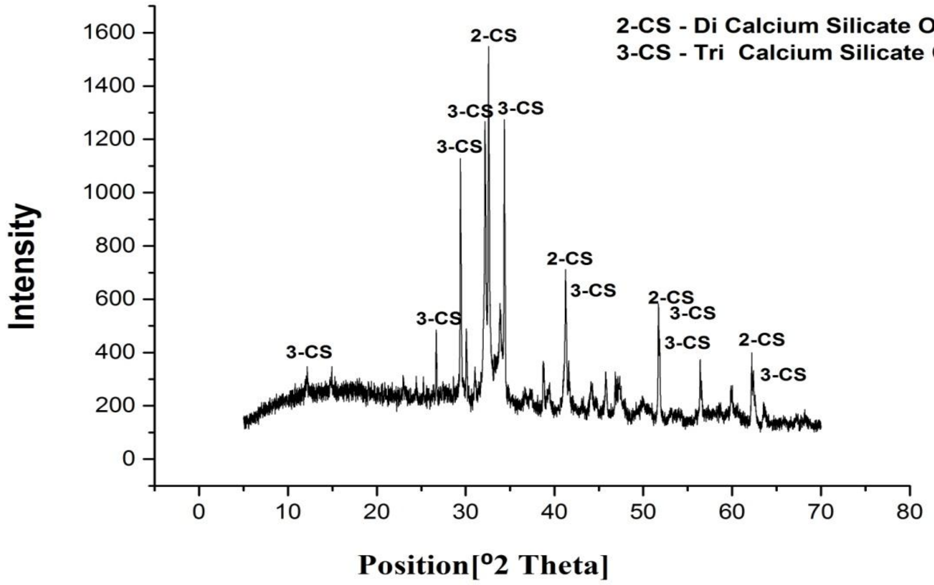


Figure 4.9 (a): X-ray diffraction pattern of Ordinary Portland Cement (OPC)

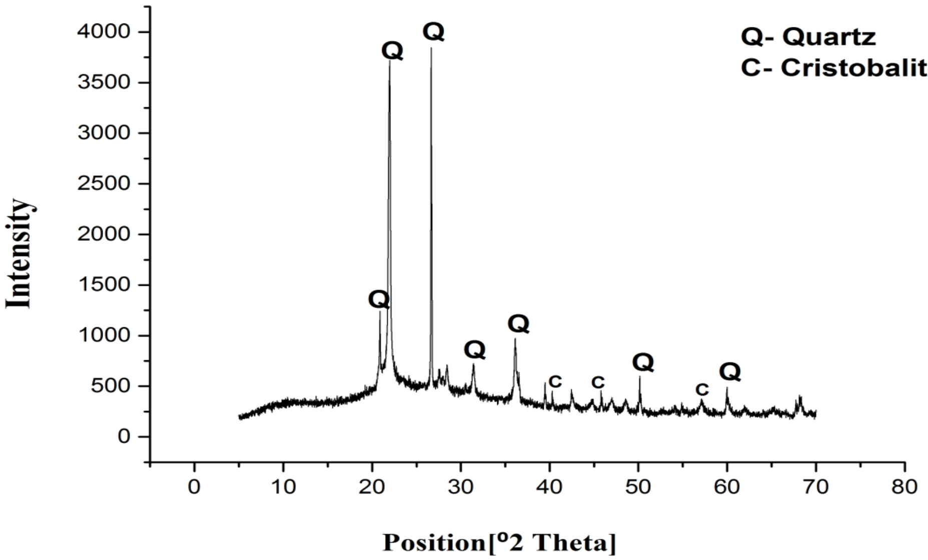


Figure 4.9 (b): X-ray diffraction pattern of Rice Husk Ash (RHA)

In all the concrete mixes, C_2S, C_3S, and C_4AF peaks are not visible indicating that they may be totally consumed or overlapping of the peaks of un hydrated cement by that of Si may have occurred as all analyzed mixes were concrete specimens with large number of aggregate particles containing quartz which resulted in intensive Si peaks.

SiO_2 peak indicating free silica, in CM mix was observed at 6600. For mix 10RHA SiO_2 peak indicating free silica was observed at 3700. For the mix 15RHA the intensity of free silica decreased to 2000.There is more formation of C-S-H gel, this is the main reason for increase in strength as compared to other mixes Then again for mix 20RHA the intensity of free silica increased to 5900, which is still less than 0RHA. The increase in basically due to decrease in cement content, which results in less production of hydration product. So more unreacted free silica is left in the matrix.

Phase determination could not be carried out as the mixes are complex and XRD analysis is done for single crystalline and polycrystalline (two) for phase determination.

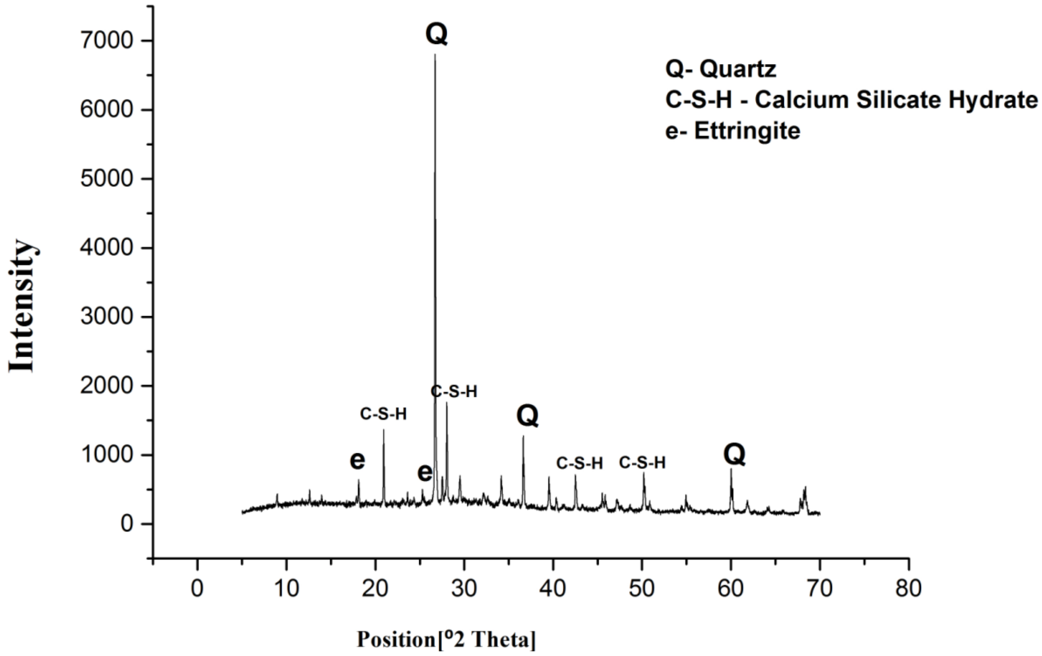


Figure 4.9 (c): X-ray diffraction pattern of 0RHA (Controlled) mix

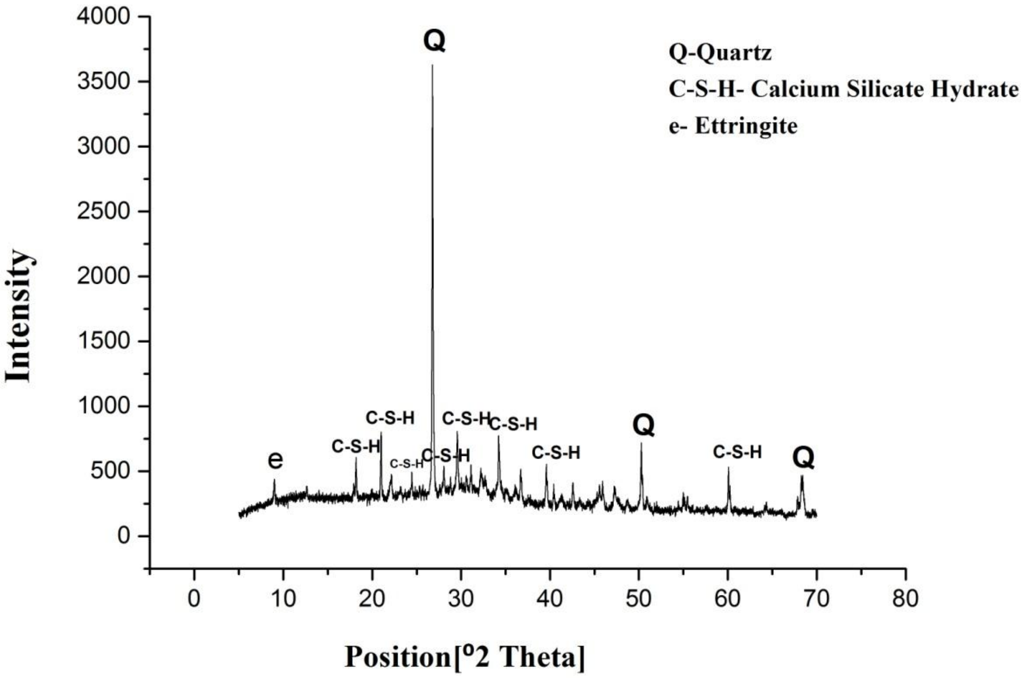


Figure 4.9 (d): X-ray diffraction pattern of 10RHA mix

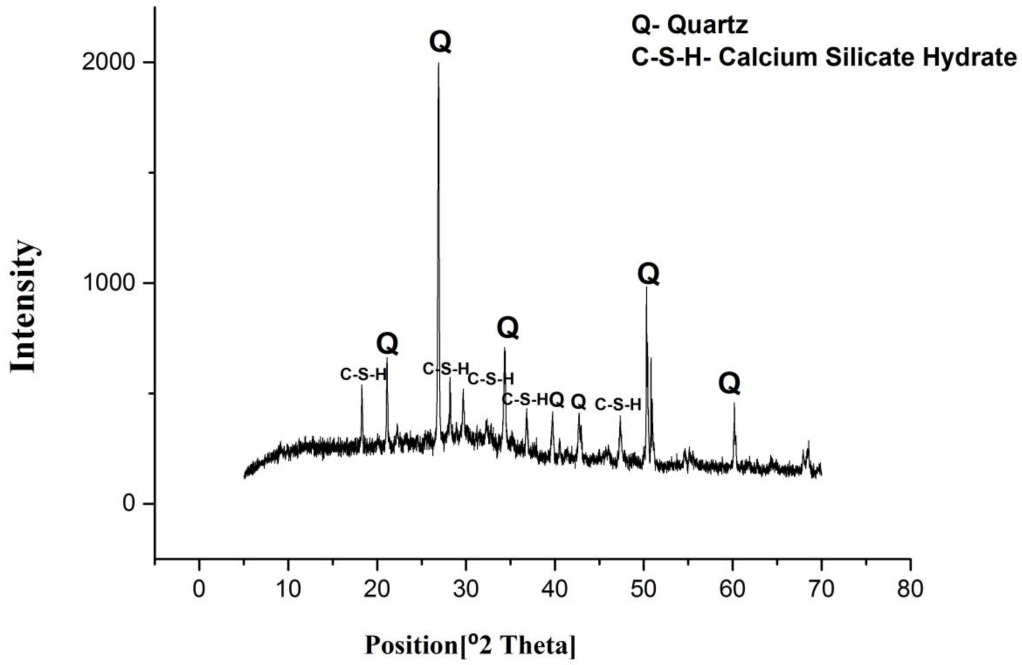


Figure 4.9 (e): X-ray diffraction pattern of 15RHA mix

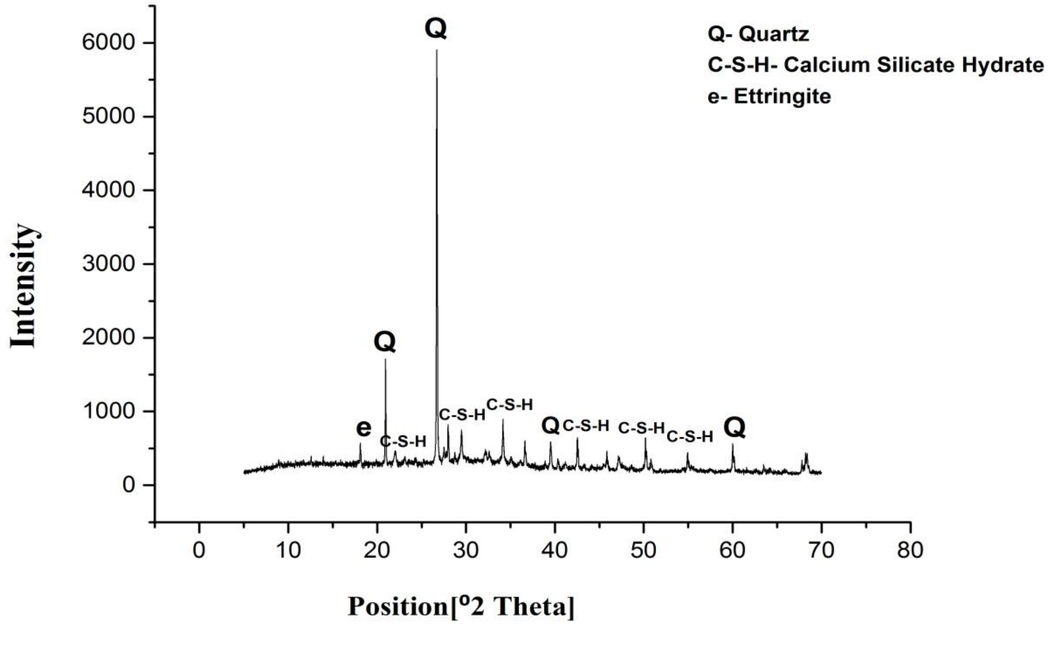


Figure 4.9 (f): X-ray diffraction pattern of 20RHA mix

CHAPTER 5 CONCLUSIONS

5.1 General

The strength and durability characteristics of Self compacting concrete (SCC) incorporating Rice Husk Ash (RHA) have been computed by replacing 10%, 15%, and 20% cement by rice husk ask. The inclusion of rice husk ash as replacement of cement does not affect the strength properties negatively as the strength remains within limits. The concrete was endowed with comparable mechanical properties and greater resistance to aggressive agents (chemical, physical and environmental).

On the basis of present study following conclusions have been drawn.

5.2 Fresh Concrete Properties

The present results show that it is possible to design a SCC mix incorporating Rice Husk Ash (RHA) up to 15%. The SCC mixes have a slump flow in the range of 600-800 mm, V-funnel time in the range of 4-10 s, L-box ratio was greater than 0.8 for all mixes and difference in height of concrete in two compartments in U-box in the range of 5-40 mm. With increase in rice husk ash content the workability decreased.

5.3 Compressive Strength

For constant water cement ratio, compressive strength increased up to 15% replacement of cement by Rice husk ash. Above 15%, decrease in strength was observed due to reduced hydration reaction and lower cement content, but its value was still higher than controlled mix. SCC mixes develop compressive strength ranging from 29.0 to 32.6 MPa, from 36.7 to 41.2 MPa, from 39.6 to 46.4 MPa at 7, 28 and 56 days.

The increase of about 25% strength at 7 days, 33% strength at 28 days and 36% strength at 56 days were observed with increase of RHA content from control mix (0RHA) to 15RHA.

5.4 Splitting Tensile Strength

Similar trend was shown as for compressive strength. The split tensile strength increased up to 15% replacement of cement by Rice husk ash. SCC mixes develop split tensile strength ranging from 2.0 to 2.8 MPa, form 2.5 to 3.7 MPa, from 2.8 to 4.0 MPa at 7, 28 and 56 days.

5.5 Rapid Chloride Permeability Test (RCPT)

SCC mixes made with rice husk ash reduced the rapid chloride ion penetrability. Increase in replacement decreases the charge passed. Very low permeability was achieved by the mix 15RHA (15% replacement of cement by rice husk ash) and moderate permeability was recorded for mix 0RHA (0% RHA replacement).

Moderate range (less than 2837 coulombs) at 28 days was recorded for SCC mix with no replacement with Rice husk ash, Very low range (less than 945 coulombs) at 28 days was observed for mix containing rice husk ash.

5.6 Porosity

With the inclusion of rice husk ash into the matrix, reduced the pores for all mixes. Porosity decreased with increase in curing time due to increased rate of hydration with time.

Lowest porosity is obtained by the mix 15RHA. All the values obtained were less than the values obtained by controlled mix containing 0% replacement by rice husk ash.

This concludes that inclusion of rice husk ash gives positive effect on the major durability property of SCC.

5.7 Scanning Electron Microscope (SEM)

XRD and SEM analysis reveals the increased formation of CSH gel for all mixes which supports the increased compressive strength in 15% rice husk ash concrete. Pores and cracking were observed maximum for controlled mix. Most dense structure was observed in case of 15% replacement with rice husk ash that results in highest compressive strength for mix 15RHA.

5.8 X- Ray Diffraction

XRD analysis revealed the increased formation of C-S-H gel which supports the increase in compressive strength for the mix containing rice husk ash. Small quantity of non expansive ettringite was observed.

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