CHAPTER-1

INTRODUCTION

1.1 NEED FOR DEVELOPMENT OF SELF COMPACTING CONCRETE

Concrete technology has made tremendous strides in the past decade. Concrete is now no longer a material consisting of cement, aggregates, water and admixtures but it is an engineered material with several new constituents performing satisfactorily under different exposure conditions. Concrete today can be a tailor made for specific applications and it contains different materials like micro silica, colloidal silica and many other binders, fillers and pozzolonic materials. The development of specifying a concrete according to its performance and requirements, rather than the constituents and ingredients have opened innumerable opportunities for producers of concrete and users to design concrete to suit their specific requirements. One of the most outstanding advances in the concrete technology in the last decade is “self compacting concrete” (SCC). The concept of Self-compacting was proposed in 1986 by Professor Hajime Okamura. However the prototype was first developed in 1988 in Japan, by Professor Ozawa at the University of Tokyo. Self-Compacting Concrete is a High Performance Concrete, which distinguishes itself with self-consolidation properties with high flowability. At Present self-compacting concrete can be considered as an advanced construction material. As the name suggests, it does not require to be vibrated to achieve full compaction. This offers many
benefits and advantages over conventional concrete. SCC has an improved quality of concrete and reduction of on-site repairs, faster construction times, lower overall costs and facilitation of introduction of automation into concrete construction. An important improvement of health and safety is also achieved through elimination of handling of vibrators and a substantial reduction of environmental noise loading in and around the site. The composition of SCC mix includes substantial proportion of fine-grained inorganic materials and this gives possibilities for utilization of mineral admixtures, which are currently waste products with no practical applications and are costly to dispose off. Due to its specific properties, SCC may contribute a significant improvement of the quality of concrete structure and open up new fields for the application of concrete and offer a rapid rate of concrete placement, with faster construction times and compacts into every corner of a formwork. It is also referred as self-leveling concrete, super workable concrete, self consolidating concrete, high flowability concrete, non-living concrete, etc.

1.2 APPLICATIONS OF SCC

The principle of self-compacting concrete is not new. Specific applications such as under water concreting always require fresh concrete, which could be placed without the need of compaction, where vibration is simply impossible. Early self-compacting concretes relied on very high contents of cement paste. The mix requires
specialized and well-controlled placing methods in order to avoid segregation. The high contents of cement paste made them prone to more shrinkage and high heat generation. The overall cost was very high and applications remained very limited. This led to the development of admixtures, which served the purpose of producing SCC. The admixtures consist of High Range Water Reducing Agents (HRWRA) and Viscosity Modifying Agents (VMA) which change the rheological properties of concrete.

### 1.3 BENEFITS OF SELF COMPACTING CONCRETE

Self-compacting concrete can be considered as an advanced construction material. The SCC as the name suggests, does not require to be vibrated to achieve full compaction. This offers many benefits over conventional concrete.

1. SCC can be placed at a faster rate with no mechanical vibration and less screeding, resulting in savings in placement costs.
2. SCC has improved and has more uniform architectural surface finish with little remedial surface work.
3. Ease of filling restricted sections and hard to reach areas.
4. SCC can be used to create structural and architectural shapes and surface finishes not achievable with conventional concrete.
5. Improved consolidations around reinforcement and bond with reinforcement.
6. Substantial reduction of environmental noise around the construction site.

7. Possibilities for utilization of “dusts”, which are currently waste products having no practical applications and which are costly to dispose off.

8. Thinner concrete sections.

9. Greater flexibility in design

10. Ease of placement and shorter construction period’s results in cost saving through reduced equipment and labour requirement.

11. The high resistance to external segregation and the mixture’s self-compacting ability allow the elimination of macro defects, air bubbles and honeycombs which lead to improved mechanical performance and structure durability.

### 1.4 DIS-ADVANTAGES OF SELF-COMPACTING CONCRETE

The only disadvantage associated with SCC is that the test methods for workability properties of SCC have not yet been standardized. There is no customized procedure for mix proportion.

### 1.5 BASIC PRINCIPLES OF SELF-COMPACTING CONCRETE

SCC consolidates itself due to its self-weight and is de-aerated almost completely while filling the formwork. As defined earlier, no additional inner or outer vibration is necessary for the compaction. In
structural members even with high percentage of reinforcement, it fills all voids and gaps completely. SCC flows like “honey” and has nearly a horizontal concrete level after placing (less screeding).

With regard to its composition, self-compacting concrete consists of the same components as conventionally vibrated normal concrete, which are cement, aggregates, water additives and admixtures. In principle, the properties of the fresh and hardened SCC, which depends on the mix design, should not be different from Normal Concrete (N.C.) the only exception is the consistency. However, the high amount of super-plasticizer for reduction of the liquid limit and for better workability, the high powder content as “lubricant” for the coarse aggregates, as well as the use of viscosity-agents to increase the viscosity of the concrete have to be taken into account. Self-compacting concrete should have a Slump Flow ($S_f$) greater than 65 (approximately) ($S_f > 65\, \text{cm}$) after pulling the flow cone.

Fig. 1.1 Basic principles for production of SCC
1.6 MANUFACTURING OF SELF-COMPACTING CONCRETE

Self-compacting concrete should be so designed, that it would level by itself (self-leveling) and further it would deform itself by its weight. This would achieve no air entrapment and ideal fair faced exposed surfaces. The design of SCC is totally different from flowing concrete. The major difficulty involved in development of SCC, was on account of contradictory factors that the concrete should be fully flowable but without bleeding or segregation. It is therefore required that the cement and mortar of the SCC should have higher viscosity to ensure flowability while maintaining non-sedimentation of bigger aggregates.

In practice, three types of Self-Compacting Concretes are available to meet the different concrete performance requirements. The three concepts for production of SCC are shown in Fig.1.2

![Diagram of Types of SCC]

**Fig. 1.2 Different concepts for production of SCC**
1) **Powder type**

This is proportioned to give the required self-compactability by reducing the water-powder (material < 0.01 mm.) ratio and provides adequate segregation resistance. SuperPlasticizers (S.P.) and air entraining admixtures give the required deformability.

2) **Viscosity agent type**

This type is proportioned to provide self-compaction by the use of a Viscosity Modifying Admixture (VMA) to provide segregation resistance. Superplasticizers and air-entrainment admixtures are used as in powder type SCC for obtaining the desired deformability.

3) **Combination type**

This type is proportioned so as to obtain self-compactability mainly by reducing the water-powder ratio. As in the powder type, a Viscosity Modifying Admixture is added to reduce the quality fluctuations of the fresh concrete properties (flow and segregation resistance) due to the variation of the surface moisture content of the aggregates and their gradations during the production. This facilitates the proper production control of the concrete. The powder (all material <0.1mm) play an important role in proportioning of SCC. The powder type and the combination type of SCC have a reduced water/powder ratio. This means that for these types of SCC the powder content (cement + fillers + fines from the aggregate) is usually in the range of 500 to 600 kg/m³. Basic properties of SCC are **plastic viscosity**, **deformability**, **flowability** and **resistance to segregation**. Several components of
concrete are used to provide and control these properties. It is important to have a stable equilibrium between the plastic viscosity and the yield stress in a SCC. If this equilibrium is not maintained then several problems may arise such as insufficient flow, which will affect the filling ability leading to incomplete filling of the forms or too low plastic viscosity, which may cause segregation. The effect of each component may be summarized as follows:

- Variations in the powder content affects mainly the yield stress and to some extent the plastic viscosity.
- Air content affects mainly the plastic viscosity
- Water affects the yield stress and the plastic viscosity
- Superplasticizer dosage affects mainly the yield stress and marginally the plastic viscosity
- Viscosity Modifying Agent affects mainly the plastic viscosity

At normal mixing or placing conditions, the ionic interaction of the viscosity modifier provides the homogeneity of the mix and prevents segregation. The balance between the yield stress and the plastic viscosity is the key to the appropriate SCC rheology. Hence a number of points have to be considered while designing SCC.

1.7 DEFINITIONS

1.7.1 Additives

In concrete finely-divided inorganic material is used in order to improve certain properties or to achieve special properties. This specification refers to two types of inorganic additions:
- Nearly inert additions
- Pozzolanic or latent hydraulic additions

1.7.2 Admixture

The material added during the mixing process of concrete in small quantities to reduce the segregation and sensitivity of the mix due to variation in other constituents especially to moisture content.

1.7.3 Binder

The combined cement and hydraulic addition in a self-compacting concrete.

1.7.4 Powder (Fines)

Material of particle size smaller than 0.125 mm. It will also include this size fraction of the sand.

1.7.5 Mortar

The fraction of the concrete comprising paste plus those aggregates less than 4 mm.

1.7.6 Paste

The fraction of the concrete comprising powder plus water and air.

1.7.7 Filling Ability (Unconfined Flowability)

The ability of SCC to flow into and fill completely all spaces within the formwork, under its own weight

1.7.8 Passing Ability (Confined Flowability)

The ability of SCC to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking.
1.7.9 Segregation Resistance (Stability)

The ability of SCC to remain homogeneous in composition during transport and placing.

1.8 MATERIALS AND TEST METHODS

1.8.1 GENERAL

The basic components of the mix composition of SCC are the same as used in conventional concrete. However, to obtain the requisite properties of fresh concrete, in SCC a higher proportion of ultrafine materials and the incorporation of chemical admixtures, in particular effective super plasticizers, are necessary. Generally used filler materials are fly ash, limestone powder, blast furnace slag, and silica fume and quartzite powder.

A comparison of a typical mix composition of SCC and conventional concrete is shown in Fig. 1.3

![Fig. 1.3 Mix composition of SCC in comparison with normal vibrated concrete.](image-url)
1.8.2 The materials used in producing SCC are

1) Cement
2) Fine aggregate
3) Coarse aggregate
4) Water
5) Mineral admixtures
6) Chemical admixtures

The ingredients of a concrete can be classified into two groups namely active and inactive. The active group consists of cement and water, where as inactive comprises fine and coarse aggregates. The inactive group is also some times called the inactive index.

1.8.2.1 Cement

Cement is first, to bind the fine aggregate and coarse aggregate together and fill the voids in between coarse aggregate and fine aggregate particles to form a compact mass. Cement constitutes to only 10% of the volume of the mix, it is the active portion of the binding medium and the only scientifically controlled ingredient of the concrete.

Selection of the type of cement will depend on the overall requirements for the concrete, such as strength, durability etc. The typical content of cement in SCC is 350 - 600kg/m\(^3\). The cement content more than 500 kg/m\(^3\) can be dangerous and may increase the shrinkage. The cement less than 350 kg/m\(^3\) may only be suitable with the inclusion of other fine filler, such as fly ash, pozzolana, etc.
Too much cement content makes the mixture “sticky” and decreases the workability.

1.8.2.2 Aggregates

Aggregates are one of the important constituents in concrete. They are the body to the concrete that reduce shrinkage and effect economy. Aggregates were considered as chemically inert materials. The mere fact is that the aggregates occupy 70-80% of the volume of concrete. To know more about the concrete it is very essential that one should know more about the aggregates, which constitutes major volume in concrete. Water and aggregates are natural materials and can vary to any extent in many of their properties. Aggregates can be classified on the basis of the size of the aggregates as coarse aggregate and fine aggregate.

1.8.2.3 Coarse Aggregate

The aggregate of size greater than 4.75mm is considered as coarse aggregate. For any concrete mix, the maximum size of the aggregate depends on the particular application and is generally 5-20mm. However, aggregate sizes up to 20mm or more have been used in SCC. Aggregate size, shape, content and gradation play a critical role in the successful production of SCC. During production of SCC, tests of aggregate grading and moisture content should be carried out frequently than usual, because SCC is more sensitive than normal concrete to variation. Regarding the characteristics of different types of aggregate, crushed aggregates tend to improve the strength because
of the interlocking of the angular particles, while rounded aggregates improve the flow because of lower internal friction. More coarse aggregate content can cause blockage and reduce the flowability of the concrete mix, because of contact between coarse aggregates. Additional cement required for angular aggregates are an asset to some extent by higher strengths and some times by greater durability, which is a result of interlocking texture of the hardened concrete and higher bond characteristics between aggregate and cement paste.

1.8.2.4 Fine Aggregate

Aggregate of size less than 4.75mm is considered as fine aggregate. All normal concreting sands are suitable for SCC. Both crushed and rounded sands / Siliceous and calcareous sands can be used. The fine aggregate content should be in the range of $1/4^{th}$ to $1/3^{rd}$ of the total volume of the mixture. It improves the workability. Fine aggregate plays a very important role in the reduction of segregation. More sand content in SCC increases the friction while pumping, and it also increases the paste demand for uniformity of the mixture.

The fine aggregate should be hard, durable, clean and free from adherent coatings and organic matter and shall not contain appreciable amount of clay and should be well graded. Fine aggregate is an adulterant to increase the volume of mortar. It reduces shrinkage and cracking of mortar on setting. Volume of fine aggregate fluctuates with the variations in its moisture content.
1.8.2.5 Water

Generally, cement requires about 3/10 of its weight of water for hydration. Water is an important ingredient of concrete as it actively participates in chemical reaction with cement. It also improves the workability. Since it helps to form the strength giving cement gel, the quantity and quality of water required is to be looked into carefully. This addition of water must be kept to the minimum. Adding too much water reduces the strength of concrete and also causes segregation and bleeding.

If too much water is added to the concrete, the excess water along with cement come to the surface by capillary action and this water mixture forms a scum or a thin layer of chalky material known as laitance. This laitance prevents bond formation between the successive layers of concrete and forms a plane of weakness.

The suitability of water for mixing concrete is that if water is fit for drinking; it is fit for making concrete. Some specification also accepts water of pH value between 6 and 8 for making concrete but water has to be free from organic matter.

1.8.2.6 Powders

The powder material plays an important role in SCC. To avoid segregation in SCC it requires a mortar with rich fines. For this purpose if only cement is used in large extent, it will be more costly, and at the same time leads to more heat of hydration, drying shrinkage and creep. To avoid this problem it is necessary to make
use of powder materials, which not only reduces the cost but also improves the workability properties. These powders should have the fineness same as that of cement. The incorporation of one or more powder materials has different morphology and grain-size distribution. This can improve particle packing density and reduce inter particle friction and viscosity. It improves deformability, self-compactability and stability of the SCC. These are commonly used to improve and maintain the workability, as well as to regulate the cement content and to reduce the heat of hydration. Ultra fine powders are also used to increase the stability of the mixture and to cut down the dosage of Viscosity Modifying Agent. The composition of SCC mixes includes substantial proportions of fine-grained inorganic materials; this offers possibilities for utilization of “dusts”, which are currently treated as industrial wastes.

These mineral admixtures are either inert fillers or reactive in nature. Inert fillers include Quartz powder and lime stone powder while reactive fillers are fly ash, ggbs etc. The reactive mineral admixtures affect the concrete properties in many ways.

1.8.2.7 Ground granulated blast-furnace slag (GGBS)

Granulated blast furnace slag is obtained during the manufacturing process of pig iron in blast furnace. The slag is a mixture of lime, silica, and alumina, the same oxides that make up Portland cement, but not in the same proportion. The composition of blast-furnace slag is determined by the ores, fluxing stone and
impurities in the coke charged into the blast furnace. The Silicon, Calcium, Aluminum, Magnesium, and Oxygen constitute 95% or more of the blast-furnace slag. To maximize hydraulic (cementitious) properties, the molten slag must be chilled rapidly as it leaves the blast furnace. Rapid quenching or chilling minimizes crystallization and converts the molten slag into fine-aggregate-sized particles generally smaller than a 4.75 mm (No.4) sieve, composed predominantly of glass. This product is referred to as granulated iron blast-furnace slag. By finely grinding this material GGBS is obtained. It is also used as filler in SCC.

1.8.2.8 Performance of GGBS in Concrete

Improved workability in fresh Concrete

The replacement of cement with GGBS will reduce the unit water content necessary to obtain the same slump. This reduction of unit water content will be more pronounced with increase in slag content and also on the fineness of slag. This is because of the surface configuration and particle shape of slag being different than cement particle. In addition, water used for mixing is not immediately lost, as the surface hydration of slag is slightly slower than that of cement.

Hardened concrete

Extensive research and field applications show that the presence of GGBS leads to the intrinsic properties of the concrete which result in improving durability of structure. The major advantages established by using GGBS are:
• Lower heat of hydration
• Reduced permeability
• Resistance to sulphate attack
• Resistance to chloride attack
• Resistance to alkali aggregate reaction
• Reduced leaching

The early age strength values of GGBS concrete mixtures are lower than the ordinary mixtures. The strength values of the GGBS concrete mixtures increase more than the ordinary mixtures, as the curing period is extended. After 1 year, the GGBS concrete mixtures exhibit higher strength values compared to the ordinary mixtures with same water binder ratio. The strength gain takes longer time for the GGBS concrete, since the pozzolanic reaction is slow and depends on the calcium hydroxide availability.

**Lower heat of hydration**

The hydration of the Portland cement leads to the production of portlandite crystal \([\text{Ca(OH)}_2]\) and amorphous calcium silicate hydrate gel \([\text{C}_3\text{S}_2\text{H}_3]\) \((\text{C}–\text{S}–\text{H})\) in large amounts. Hydrated cement paste involves approximately 70% C–S–H, 20% Ca \((\text{OH})_2\); 7% sulpha-aluminates and 3% secondary phases. The Ca(OH)_2 which appears as the result of the chemical reactions affect the quality of the concrete adversely by forming cavities as it is partly soluble in water and lacks enough strength. The use of GGBS has a positive effect on binding the Ca (OH)_2 compound, which decreases the quality of the concrete. At the
end of the reaction of the slag and Ca (OH)$_2$, hydration products, such as C–S–H gel, are formed. As a net result, incorporation of GGBS in concrete can contribute a great deal to reduce the adverse effect due to the “locked-in stresses and micro cracking arising from the heat evolved during cement hydration. The chemical reaction of the Portland cement is expressed as follows:

\[
\text{Cement (C}_3\text{S, C}_2\text{S)} + \text{H}_2\text{O (H)} \rightarrow \text{CSH–gel + Ca (OH)}_2 \text{(CH)}
\]

The pozzolanic reaction is \(\text{Ca (OH)}_2 \text{(CH)} + \text{SiO}_2 \text{(S)} + \text{H}_2\text{O (H)} \rightarrow \text{CSH}\)

It can be observed from the above reactions; Calcium hydroxide is produced by the hydration of Portland cement and consumed by the pozzolanic reaction. So it can be said that the pozzolanic reaction can only take place after the hydration of Portland cement starts.

**Reduced permeability**

Permeability is the key factor affecting the chemical attacks on the concrete and the reinforced steel. Many studies have shown that the concrete containing GGBS has much more reduced pore structure than OPC Concrete due to denser gel formation during Hydration Process.

**High resistance to sulphate attack**

Chemical reaction between sulphate ions in soil/water and C$_3$A content in cement results in the formation of ettringite which can lead to excessive expansion and cracking in the concrete. Partial replacement of OPC by GGBS increases the resistance of concrete to
sulphate attack and this is acknowledged in all major European Codes of Practice. The major factors influencing the increased resistance are:

a) The ratio of GGBS to OPC in the Concrete
b) Low Permeability of the concrete
c) Low C\textsubscript{3}A content in cement composite
d) Depletion of Calcium Hydroxide content due to reaction with GGBS in the concrete.

**Resistance to chloride attack**

Lower permeability of concrete is the only way that can reduce the intensity of chloride attack on a concrete structure. It is proved that concrete containing GGBS possesses much lower chloride permeability than the corresponding OPC Concrete. This reduction in diffusivity would appear to be due to two mechanisms:

a) The incorporation of GGBS reduces the permeability of the concrete.

b) Hardened paste of GGBS bind greater amounts of chloride than that of the OPC, resulting in much lower proportion of free chloride in the pore solution.

Hence, concrete containing GGBS provide greatly increased protection for steel reinforcement in environments that subjected to chloride attack.

**Resistance to alkali-aggregate reaction (AAR)**

Deleterious reactions between certain types of Reactive Aggregates in concrete with alkalies (K\textsubscript{2}O and Na\textsubscript{2}O) in cement/water are known to cause cracking, expansion and distress to concrete
dams, bridges etc. Concrete made with GGBS has 85% less expansion due to Alkali-Aggregate Reaction than OPC. Low Alkali-ion diffusion rate and low permeability to water of GGBS Concrete reduces the harmful reaction. Because of these two factors any expansion that occurs may develop 100 to 1000 times late in a GGBS Concrete than in OPC Concrete. Hence, GGBS can be used safely where Reactive Aggregates are used in the construction.

**Reduced leaching**

Calcium Hydroxide Ca (OH)$_2$ reacts with CO$_2$ in air to form Calcium carbonate (CaCO$_3$) which is in white colour and form white patches on the concrete finished surfaces. Development of white patches is more with high grade OPC due to high C$_3$S content and more liberation of Ca (OH)$_2$, than concrete with GGBS.

1.8.2.9 Chemical Admixtures

The most commonly used chemical admixtures in SCC are

- High Range Water Reducers (HRWR)
- Viscosity Modifying Agent (VMA).

**High Range Water Reducers (HRWR)/Superplasticizer**

In order to maintain deformability along with flowability in paste, a superplasticizer is must in the concrete. To limit the amount of water required for obtaining a fluid mixture, super plasticizers are necessary. With a superplasticizer, the paste can be made flowable with little decrease in viscosity. The superplasticizer reduces the w/c ratio.
The requirements for superplasticizer in SCC are summarized below:

- High dispersing effect for low water to powder ratio.
- Maintenance of the dispersing effect for at least two hours after mixing.
- Less sensitivity to temperature changes.

For achieving the SCC, an optimum combination of w/c ratio and super plasticizer dosage can be derived for fixed aggregate content in concrete. The traditional high range water reducers are either melamine or naphthalene based sulphonates. They cover around the cement granules at a very early stage of the concrete mixing process. The sulphonic groups of the polymer chains increase the negative charge of the cement particle surface and disperse these particles by electrostatic repulsion. The electrostatic mechanism causes the cement paste to disperse and has the positive consequences of requiring less mixing water for a given concrete or making it more flowable.

One of the new generation high range water reducers is polycarboxylic ether with long side chains. At the beginning of the mixing process it initiates the same type of mechanism as the traditional HRWR, additionally the side chains linked to the polymer’s backbone generates a stearic hindrance, which greatly stabilizes the cement particles ability to separate and disperse. With this process, flowable concrete with greatly reduced water content is obtained. This new range carboxylic ether has been found to have lower slump loss.
**Viscosity Modifying Agent (VMA)**

Viscosity modifying agents are water-soluble polymers that increase the viscosity of mixing water and enhance the ability of concrete to retain its constituted suspension. These admixtures are also known as Anti-washout admixtures or Anti-Bleeding admixtures. The basic function of VMA is to stabilize the concrete mixture. VMA restricts the dosage of superplasticizer. Commonly used viscosity modifying agents in concrete include cellulose derivatives and polysaccharides of microbial sources.

Some of the viscosities modifying agents are

- Welan gum
- Hydroxyl Propyl Methyl Cellulose (HPMC)
- Guar gum
- Sodium alginate
- Hydroxyl Propyl Starch, etc.

The incorporation of VMA affects the aqueous phase of the cement paste where chains of the water-soluble polymer can imbibe some of the free water in the system, thus enhancing the viscosity of the cement paste. As a result, less free water can be available for bleeding. The enhanced viscosity of the paste to suspend solid particles reduces sedimentation.
1.8.2.10 Rice Husk Ash (RHA)

**Production, sources and utilization**

Worldwide more than 100 million tonnes per year of rice husks are available worldwide for disposal. Each ton of paddy rice produces about 200 kg of husks, which on combustion yield approximately 40 kg of ash. This means that there is a potential for producing 20 million tonnes of rice husk ash every year. The ash formed during open-field burning or uncontrolled combustion generally contains a large proportion of silica and when ground to a very fine particle size develops highly pozzolanic properties. The combustion of rice husks produces approximately 20% high silica ash. As crystalline silica is hazardous to human health, the burning temperature of rice husk ash must be controlled to keep silica in an amorphous state. The main use of RHA as mineral admixture in concrete is to reduce the permeability. A number of investigations have been reported using RHA as mineral admixture, which acts as microfillers and thereby the micro structure of the hardened cement material becomes denser and stronger which improves its strength and durability characteristics. Many concrete technologists all over the globe have reported an excellent performance of RHA as mineral admixture. RHA blended concretes decreases the temperature effect that occurs during cement hydration. It also increases the initial and final setting time of cement. Ultrafine supplementary cementitious materials like GGBS and RHA has the ability to pack more closely to aggregate surface. The effect of
the presence of the mineral admixtures in the interfacial zone results in the production of a more homogenous microstructure and a better bond between paste and aggregate.

Rice husk ash is highly reactive pozzolanic material, which derive their lime reactivity from the combination of two factors, namely totally non-crystalline structure and high surface area. RHA contains high amount of SiO$_2$, most of which is in amorphous form which makes RHA a pozzolanic material. Amorphous silica can be produced by maintaining combustion temperature at 500$^\circ$C under oxidising conditions. The rice husk ash which contains as much as 85-95% silica is highly reactive. Addition of finely ground RHA with a fineness of above 16000 sq.cm/gm improves the microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in SCC.

Rice Husk is made into Ash by incineration and used as a partial substitute replacement for the old Portland cement. RHA contains the much needed silica necessary for the strength of cement products; the silica content obtained depends on the temperature of incineration. The silica content varies from 82% to 94.7% by open burning at 1000$^\circ$C. Even though at temperature below 600$^\circ$C and above 1000$^\circ$C RHA results in crystalline structure, the grinding of ash increases its reactivity. Amorphous ash which contains highly reactive silica is formed by burning upto a maximum of 700$^\circ$C -800$^\circ$C. Above
800°c crystalline silica with low reactivity is formed, and at temperature below 500 °c formation of amorphous silica is unlikely.

Portland cement is primarily made of silicious and calcareous materials. When RHA is mixed with cements or lime the highly reactive silica reacts vigoursly resulting in a good binding material. Besides temperature of burning, fineness of ash plays a vital role in the reactivity of silica. The reaction product of lime and silica is calcium silicate hydrate, C-S-H gel, which is the strength of rice husk ash cement.

The setting process leads to development or enhancement of strength and is given as
SIO₂ (RHA) + H₂O → C-S-H + Unreacted silica

C₃S (Portland cement) + H₂O → C-S-H + Ca(OH)₂

Portland cement + RHA + H₂O → C-S-H + unreacted silica

Where C-Cao, S-SIO₂, H-H₂O, C-S-H - Calcium Silicate Hydrate.

Additionally RHA blended concrete can decrease the total porosity of concrete and modify pore structure of the cement mortar, concrete and significantly reduce the permeability which allows the influence of harmful ions leading to the deterioration of the concrete matrix. Partial replacement of cement with RHA reduces the water penetration into concrete by capillary action.

1.9 Mix Composition as per EFNARC Specifications

Indicative typical ranges of proportions and quantities in order to obtain self-compactability are given below. Further modifications will be necessary to meet strength and other performance requirements.

- Water/powder ratio by volume of 0.80 to 1.10.
- Total powder content - 160 to 240 litres (400-600 kg) per cubic meter.
- Coarse aggregate content normally 28 to 35 per cent by volume of the mix.
- Water/cement ratio is selected based on requirements in EN 206. Typically water content does not exceed 200 litre/m³.
- The sand content balances the volume of the other constituents.
Generally, it is advisable to design conservatively to ensure that the concrete is capable of maintaining its specified fresh properties despite anticipated variations in raw material quality. Some variation in aggregate moisture content should also be expected and allowed for at mix design stage. Normally, viscosity-modifying admixtures are useful for compensating for the fluctuations due to any variations of the sand grading and the moisture content of the aggregates.

1.10. TESTING METHODS FOR SELF-COMPACTABILITY

SCC tests methods have two main purposes. First is to judge whether the concrete is self-compactable or not, and the second is to evaluate deformability or viscosity for estimating proper mix proportionality. Conventional workability tests, devised for normal range of concrete mixture are not adequate for SCC, because they are not sensitive enough to detect the tendency to segregation. Therefore test equipments were fabricated for judging the following characteristics:-

- Filling ability
- Passing ability
- Resistance to segregation

Many different test methods have been developed to characterize the properties of SCC. So far no single method or combination of methods has achieved universal approval. Similarly no single method has been found which characterizes all the relevant workability aspects and hence, each mix design has been tested by more than one test method.
for the different workability parameters. Following are the existing tests for fresh SCC.

**Table 1.10.1 List of Testing Methods for Workability Properties of SCC**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Method</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slump-flow by Abrams cone</td>
<td>Filling ability</td>
</tr>
<tr>
<td>2</td>
<td>T&lt;sub&gt;50cm&lt;/sub&gt; slump flow</td>
<td>Filling ability</td>
</tr>
<tr>
<td>3</td>
<td>J-ring</td>
<td>Passing ability</td>
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<td>4</td>
<td>V-funnel</td>
<td>Filling ability</td>
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<td>5</td>
<td>V-funnel at T&lt;sub&gt;5&lt;/sub&gt; minutes</td>
<td>Segregation resistance</td>
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<td>U-box</td>
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<td>9</td>
<td>GTM screen stability test</td>
<td>Segregation resistance</td>
</tr>
<tr>
<td>10</td>
<td>Orimet</td>
<td>Filling ability</td>
</tr>
</tbody>
</table>

### 1.11 MIX COMPOSITION

#### 1.11.1 General

The mix composition shall satisfy the total performance criteria for the concrete in both the fresh and hardened states.

#### 1.11.2 Mix Proportioning

Before any SCC is produced and used at site the mix has to be designed and tested. In this process, local materials should be tested to achieve new concrete mixes with right mixing sequence and mixing
time valid for the plant and also suitable for the element to be cast. Various kinds of fillers can result in different strength, shrinkage and creep but they will usually not be higher than that of conventional concrete.

To achieve fluidity, homogeneity Dr Okamura [63] focused on three different aspects:

- Reduction of coarse aggregate content in order to reduce the friction, or the frequency of collision between the particles and increasing the overall fluidity of concrete.
- Increasing the paste content to further increase fluidity.
- Managing the paste viscosity to reduce the risk of aggregate blocking when the concrete flows through obstacles.

1.11.3 Mix Design Principles

The flowability and viscosity of the paste should be adjusted and balanced by careful selection, proportioning of the cement and additives by limiting water/powder ratio and then by adding superplasticisers and viscosity modifying agents. By controlling precisely these components of SCC, their compatibility and interaction, good filling and passing ability, resistance to segregation can be achieved. For controlling temperature rise and shrinkage cracking as well as strength, the powder ratio in the concrete can be increased. The paste is the vehicle for the movement of aggregate therefore the volume of the paste must be greater than void volume in
the aggregate. The coarse to fine aggregate ratio in the mix should be low to achieve a good passing ability between congested reinforcement. So to achieve fluidity, homogeneity Prof. Okamura focused on three different aspects:

- Reduction of coarse aggregate content in order to reduce the friction, or the frequency of collision between the particles and there by increasing the overall fluidity of concrete.
- Increasing the paste content to further increase fluidity.
- Managing the paste viscosity to reduce the risk of aggregate blocking when the concrete flows through obstacles.

There are no codal specifications for self compacting concrete in any country except the guide lines by EFNARC [103], European federation for specialist construction chemicals and concrete systems formulated in Europe.

1.11.4 Various Methods of Mix Design

One of the significant limitations in adopting self compacting concrete in India is the lack of availability of appropriate mixture proportioning methods. SCC requires some special considerations in mixture proportioning, since the required flowing ability cannot be achieved by just increasing the water content of the mixture. In the mixture proportioning of SCC the quantities to be determined are air, water, cement, filler, fine and coarse aggregate apart from the dosages of superplasticizer and viscosity modifying agent. All the mixture
proportioning methods given below involve trial castings and corrections. Different methods available are:
2. Sedran et al Method.
3. Method proposed by Gomes, Ravindra Gettu et al [77].
4. Nan-Su et al Method [57].
5. Method proposed by Jagadish Vengala.
6. European practice and specifications [95].

1.11.5 Workability of Self Compacting Concrete

- A good workable self compacting concrete will have slump value more than 600mm without segregation.
- If required it shall withstand a slope of 3% in case of horizontal surface
- It shall remain self compacting and flowable for at least 90 minutes.
- If required self compacting concrete shall be pumpable for at least 90 min. and through pipes with a length of at least 100 m.

1.11.6 MECHANICAL CHARACTERISTICS

The differences between the hardened properties of conventional concrete and self compacting concrete are mentioned below.
1.11.6.1. **Utilisation of high content of admixtures**

Studies done reveal that the addition of small percentages of superplasticisers in SCC i.e. up to 10% and usage of proper amount of high range water reducing admixture decreases the viscosity of the paste reducing water demand and risk of bleeding. The usage of admixtures improves the rheological properties of SCC and reduces cracking of concrete due to reduced heat of hydration and hence can be used in SCC as filler. The addition of concrete additives and admixtures is an exception in the production of conventional concrete, but is necessary for SCC and their percentage at SCC is considerably higher.

1.11.6.2. **Better microstructure and homogeneity of SCC**

The reasons for better performance of SCC attribute to better microstructure and homogeneity. Many investigations, carried out by means of efficient microscopes etc, have shown an improved microstructure of SCC opposite to conventional concrete. The void ratio of SCC in interfacial transition zone between cement paste and aggregate has been found lower and the pores have been distributed much more evenly.

The mechanical characteristics of SCC are as follows.

- Characteristic compressive strength at 28 days shall be 25-60 MPa.
- Early age compressive strength shall be 5-20 MPa at 12-15 hours at 20° C.
- Creep and shrinkage will be Normal.
Table 1.11.1 Limitations on SCC material proportions

<table>
<thead>
<tr>
<th>Material</th>
<th>High fines</th>
<th>VMA</th>
<th>Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cementations (kg/m³)</td>
<td>450-600</td>
<td>385-450</td>
<td>385-450</td>
</tr>
<tr>
<td>Water/cementitious material</td>
<td>0.28-0.45</td>
<td>0.28-0.45</td>
<td>0.28-0.45</td>
</tr>
<tr>
<td>Fine aggregate / Mortar (%)</td>
<td>35-45</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Fine aggregate / Total aggregate (%)</td>
<td>50-58</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Coarse aggregate / Total Mix (%)</td>
<td>25-48</td>
<td>45-48</td>
<td>28-48</td>
</tr>
</tbody>
</table>

1.12. ADMIXTURES

An admixture is a material other than water, aggregates and hydraulic cement used as an ingredient of concrete or mortar added to the batch immediately before or during mixing to impart new properties or to modify the properties of the mix.

The basic components for the mix composition of SCC are the same as used in conventional concrete. However to obtain the required properties of fresh and hardened concrete, in SCC a higher proportion of ultra fine materials and the incorporation of chemical admixtures particularly an effective super plasticizer, are necessary. Due to the fresh property requirements of SCC, inert and pozzolanic/hydraulic additions are commonly used to improve and maintain cohesion and segregation resistance. The addition will also regulate the cement content in order to reduce the heat of hydration.
and thermal shrinkage. Different types of admixtures used are broadly classified into mineral and chemical admixtures.

1.13 MINERAL ADMIXTURES

1.13.1 Uses of Mineral Admixtures

The benefits of mineral admixtures may be broadly classified into three categories viz engineering benefits, economic benefits and ecological benefits.

1. Engineering Benefits

Incorporation of finely divided particles into a concrete mixture tends to improve the workability and reduce water requirement at a given consistency (except silica fume). There is an enhancement of ultimate strength, impermeability and durability to chemical attack. An improved resistance to thermal cracking is obtained due to the lower heat of hydration of blended cements and increased tensile strain capacity of concrete containing mineral admixtures.

2. Economic Benefits

Portland cement represents the most expensive component of a concrete mixture. Most of the pozzolanic and cementitious materials in use today are industrial by-products, which require no expenditure of energy for use as mineral admixtures. When used as partial cement replacement, up to 70% cement by mass, mineral admixtures can result in substantial energy and cost savings.
3. Ecological Benefits

The total volume of pozzolanic and cementitious by-products generated every year by thermal power plants and metallurgical industries exceed 900 million tonnes. The cement and concrete industry preferred disposal of by-product mineral admixtures because most of the harmful metals can be safely incorporated into the hydration products of cement.

Every tonne of Portland cement production is accompanied by a similar amount of carbon dioxide as a by-product, which is released into the environment. This means that Portland cement production of one billion tonnes per year releases one billion tonnes of CO$_2$ into the atmosphere, which is a primary factor in the “Green House” effect. In the interest of the environmental protection, it is therefore desirable that the rising cement demand in the world is met by higher rates of utilization of admixtures used as supplementary cementing materials. Some of the mineral admixtures used in SCC are Inert or semi inert mineral admixtures like powdered lime stone, dolomite, quartzite etc. Pozzolanic or latent hydraulic admixtures like fly ash, silica fume, ground granulated blast furnace slag, rice husk ash, metakaolin, ground glass etc.

1.14. CHEMICAL ADMIXTURES

Although all admixtures are chemical substances, in concrete technology the term chemical admixture is restricted to soluble
Superplasticizers or high range water reducing admixtures are an essential component of SCC. Viscosity modifying admixtures (VMA) may also be used to help reduce segregation and the sensitivity of the mix due to variations in other constituents.

1.14.1 Superplasticiser / High Range Water Reducing Admixtures

Superplasticizers are broadly classified into four groups, viz. sulphonated melamine-formaldehyde condensate (SMF), sulphonated naphthalene-formaldehyde (SNF), modified lignousulphonates (MLS) and polycyclic sulphonates, polyaromatic compounds, carbohydrate esters etc. Most available information has been obtained using SMF- and SNF-based admixtures.

**To produce concrete with low water-cement ratio:**

High-strength is achieved with low water content with the same cement content. Incorporation of superplasticizers allows this reduction without affecting workability. Water reductions of up to 30 percent can be achieved and concrete with a water-to-cement ratio as low as 0.28 has been placed successfully.

**To produce flowing concrete:**

Superplasticizers can be used to produce self-compacting, self-leveling, and flowing concretes which can be placed in heavily steel-reinforced sections and in areas that are not easily accessible.

The main objective of the present experimental investigation is study the effect of GGBS and RHA on SCC concrete, mechanical
properties, efficiency factors, stress strain behavior, flexural behavior of beams and durability factors.

There are very limited investigations reported with GGBS and RHA on SCC. Also, there is scant work reported on evaluation of efficiency factors and durability aspects of SCC made with GGBS and RHA. Keeping this in view, the present experimental investigations are taken up to study the effect of GGBS and RHA on low (M20), medium (M40) and high grade (M60) concrete. Here, M is mix and 20, 40, 60 indicate strengths at the end of 28 days curing.

The parameters involved in the study were the effect of different percentages of GGBS (increment of 5% up to 30%) on three grades of concrete, age of curing (3, 7 & 28 days), effect of RHA on three grades of concrete. The other parameters like mechanical properties like compressive strength, split tensile strength, flexural strength, efficiency factors, stress - strain behavior, flexural behaviour of beams have been studied. The durability aspects like ADF, AAF, weight loss and compressive strengths were also taken up.

This chapter has highlighted several aspects of SCC requirements, different materials involved, applications, advantages, and dis-advantages of SCC. The important strength efficiency factors and durability aspects to quantify SCC are studied in detail. The relevant literature of various researchers is given in chapter-2.