CHAPTER- 4

EXPERIMENTAL INVESTIGATIONS

4.0 INTRODUCTION

The aim of the present experimental investigations is to study the behavior of low, medium and high grades SCC of 20MPa, 40MPa and 60MPa strengths with mineral admixtures like GGBS and RHA, to obtain specific experimental data which helps to understand about the self compacting concrete and to study their structural behavior.

In the present experimental investigation, studies have been carried out on the fresh and hardened properties of SCC of three different grades with GGBS and RHA. By conducting slump cone test, V funnel test and L-box test on SCC, fresh properties like filling ability, passing ability and segregation resistance were studied. The hardened properties like compressive strength, split tensile strength, flexural strength, evaluation of strength efficiency factors of SCC, stress-strain behaviour, flexural behaviour of beams were determined by conducting suitable tests on SCC. Apart from this, the durability tests are also done on all the three grades exposed to three different acids.

Total experimental programme was taken up in various phases. They are

i. Development of three grades of SCC with GGBS as admixture and studies on fresh and hardened properties of SCC developed.
ii. Study the effect of RHA on GGBS SCC and its fresh & hardened properties.

iii. Evaluation of strength efficiency factors of SCC.

iv. Stress-Strain behavior of SCC with GGBS and RHA.

v. Study of Flexural behavior of SCC with GGBS and RHA.

vi. Development of Moment-Curvature relationships with the analytical models and their Validation.

vii. Studies on the durability of SCC with GGBS and RHA.

4.1 MATERIALS USED

4.1.1 Cement

Ordinary Portland cement available in local market of standard brand was used in the investigation. The cement used has been tested for various properties as per IS 4031-1988 and found to conform various specifications as per IS 12269-1987. Cement was conforming to 53 Grade having specific gravity 2.91.

4.1.2 Coarse Aggregate

Crushed angular granite metal of 10 mm size from local quarry was used as coarse aggregate. The cleaned coarse aggregate was tested for various properties such as specific gravity, fineness modulus, bulk modulus etc.

4.1.3 Fine Aggregate

The locally available river sand was used as fine aggregate in the present investigation. The cleaned fine aggregate was tested for various properties such as specific gravity, fineness modulus, bulk modulus etc and are conforming to standard specifications.
4.1.4 Ground Granulated Blast Furnace Slag (GGBS)

Ready to use ground granulated blast furnace slag was obtained from Penna cement company, Hyderabad and from steel plant, Vishakhapatnam. Physical and chemical properties of GGBS are in conformation with IS: 12089-1987.

4.1.5 Rice Husk Ash (RHA)

The rice husk was procured by incineration in open air. Rice husk dumped in heaps of 20-30 kgs and burnt in open ground where free access to air is available. The product was allowed to cool down for 2 days after complete burning. After that, the unburnt and under-burnt husk, which was black in colour, was separated from whitish grey ash and then ground in ball mills and in mixer to a fineness of 16,000 sq.cm/gm as determined by Blaine's air permeability test. The entire procedure is shown below

**PREPARATION OF RICE HUSK ASH**

20kg-30kg Rice Husk heaps are made

Burnt in open air in heaps of 20kg below 700ºC

Whitish grey ash is ground in ball mills

Un-burnt rice husk (black in colour) is removed

Rice Husk Ash rich in amorphous silica of fineness 16000cm²/gm obtained is highly reactive
4.1.6 Superplasticiser

The superplasticiser used was Glenium233 is based as sulphonated naphthalene formaldehyde (SNF) superplasticiser. It complies with IS: 9103–1999.

4.1.7 Viscosity Modifying Admixture (VMA)

Viscosity Modifying Agent used was Glenium Stream 2. It imparts viscosity to the SCC mix and does not allow the mix to segregate.

4.1.8 Acids

The acids used in durability studies are Na$_2$SO$_4$, H$_2$SO$_4$ and HCl.

4.1.9 Water


4.2 DEVELOPMENT OF SCC AND STUDIES ON ITS FRESH AND HARDENED PROPERTIES

The first phase of investigation was carried out to develop a SCC mix of low, medium and high strength concrete using different chemical admixtures and to study its fresh and hardened properties. The mix proportion was designed based on EFNARC method of SCC mix design. The designed mix was later extended to the mineral admixture GGBS of different percentages. Further these mixes and their combinations were blended with small quantities of RHA and its effect was observed with addition of Viscosity Modifying Agent. Finally
eight SCC mixes which have yielded high compressive strength with satisfactory fresh properties were selected and taken for next phase of investigations. This is explained in detail below.

**4.3 Mix Design and Trial Mix Proportions of Self-Compacting Concrete.**

A SCC mix as which gives a minimum compressive strength of 20 MPa, 40 MPa and 60 MPa was aimed. In the present study, the initial mix proportion was determined by EFNARC(European Federation of method of mix design and fine tuned by using different guidelines to get the mix with the required fresh and hardened properties. Detailed mix design is given in Appendix I.

Different trial mixes were attempted in the laboratory to get a SCC mix, which gives required fresh and hardened properties.

Final mass of ingredients for 1 m$^3$ of SCC for M-20 mix are as follows:

- **Mass of Cement** = 400 kg
- **Mass of water** = 180 kg
- **Mass of CA** = 780 kg
- **Mass of FA** = 844 kg
- **Superplastisiser dosage** = 0.8\% by weight of cement (bwc)

**4.3.1 Mixing of Ingredients**

The whole mixing process was carried out in a power operated concrete mixer. Fine aggregate, cement and filler material (GGBS) were put in the concrete mixer first and mixed in the dry state for few seconds. Later superplastisiser thoroughly mixed with water was added to the material in the concrete mixer. Then it was allowed to
mix thoroughly and finally coarse aggregate was added to it, mixed till a mixture of uniform colour and consistency were achieved. To produce self compacting concrete with GGBS, different percentage of GGBS were added to the mix along with coarse aggregate.

4.3.2 Testing Methods for Evaluation of Workability of SCC

The workability tests done for ordinary conventional concrete mixes are not adequate for self compacting concrete because, they are not sensitive to detect all the characteristics of self compacting concrete mix. Hence different test methods have been developed to characterize the properties of self compacting concrete, but till today no single method has been found to characterize all the relevant workability aspects of SCC. Hence each mix has to be tested by more than one testing method for different workability parameters. The following testing methods are used to characterize the workability properties and for the final acceptance of self compacting concrete mix proportions.

4.3.2.1 Slump Flow Test and T50 cm Test

Introduction

The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of Under Water Concrete (UWC). The diameter of the concrete circle is a measure for the filling ability of the concrete.

Assessment of Test

This is the most commonly used test, and gives a good assessment of filling ability. It gives indication of the ability of the
concrete to pass between reinforcement without blocking. It is also used as a routine quality control test to detect the segregation.

**Equipment**  The apparatus is shown in Fig. 4.1.

- Mould in the shape of a truncated cone with the internal dimensions 200mm diameter at the base, 100mm diameter at the top and a height of 300mm.
- Base plate of a stiff non absorbing material
- Trowel
- Scoop
- Ruler
- Stop watch

**Procedure**

- To perform this test about 6 litres of concrete is needed
- Base plate and inside of slump cone are moistened
- Base plate was placed on a stable ground and the slump cone is placed centrally on the base plate
- The cone is filled with concrete without tamping and simply the top of the concrete is leveled with the trowel
- Surplus concrete present around the base of the cone is removed
- The cone is lifted vertically and allows the concrete to flow out freely.
Simultaneously, the time taken for the concrete to reach the 500mm spread circle (T_{50cm} time) is recorded by using stopwatch.

And finally, the final diameter of the concrete in two perpendicular directions is measured.

Average of the two measured diameters is calculated (this is the slump flow in mm).

![Slump Flow Test](image)

**Fig. 4.1 Slump Flow Test**

**Interpretation of Results**

A slump flow ranging from 650 to 800mm is considered necessary for a concrete to be self-compacted. At slump flow of more than 800mm the concrete might segregate and at slump flow less than 650mm the concrete may have insufficient flow to pass through highly congested reinforcement. T_{50cm} should be 2-5 seconds. The higher the slump flow value, the greater its ability to fill formwork under its own weight. The T_{50cm} time is a secondary indication of flow. A lower time indicates greater flowability.
In case of severe segregation, most coarse aggregate will remain in the center of the pool of the concrete whereas mortar and cement paste remains at the concrete periphery. In case of minor segregation, a border of mortar without coarse aggregate can occur at the edge of the pool of concrete. If none of these phenomena appear it is no assurance that segregation will not occur since this is a time related aspect that can occur after a longer period.

4.3.2.2 V-Funnel Test

Introduction

The test was developed in Japan and used by Ozawa et al(62). This test is used to determine the filling ability of the concrete. The funnel is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus measured. After this the funnel is refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

Assessment of test

Though the test is designed to measure flowability, the test result is affected by concrete properties other than flow alone. High flow time can be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. While the apparatus is simple, the effect of the angle of the funnel, and the wall effect on the flow of concrete are not clearly defined.
**Equipment** The apparatus is shown in Fig. 4.2.

- V – funnel
- Bucket
- Trowel
- Scoop
- Stopwatch

**Procedure for Flow Time**

- To conduct this test about 12 litres of concrete is needed
- The V – funnel should be placed on firm ground
- Inside surfaces of the funnel should be moistened
- The trap door is closed and the apparatus is filled with concrete without compacting and the top of the funnel is leveled with the trowel
- The trap door should be opened within 10 seconds and the concrete is allowed 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)
- The whole test has to be performed within 5 minutes
Procedure for Flow Time at $T_{5\text{minutes}}$

- The same V-funnel is used without cleaning or moistening the inside surfaces of the funnel and the trap door is closed.
- Immediately the V-funnel is refilled with the concrete after measuring the flow time without compacting or tamping.
- The top of the funnel is leveled with the trowel.
- The trap door is opened after 5 minutes and concrete is allowed to flow under gravity after the second fill of the funnel.
- Simultaneously, start the stopwatch when the trap door is opened and record the time for the discharge to complete (the flow time at $T_{5\text{minutes}}$).

Interpretation of Result

This test measures the ease of flow of the concrete. A funnel test flow time less than 6 seconds is recommended for concrete to qualify for SCC. According to EFNARC standards a flow time ($T_f$) of 10 seconds is considered appropriate for SCC, and $T_{5\text{minutes}}$ should be less than ($T_f + 3$) seconds.

Prolonged flow times may give some indication of the susceptibility of the mix to blocking. After 5 minutes of setting, concrete will show a less continuous flow with an increase in flow time.
4.3.2.3 L Box Test

Introduction
This test is based on a Japanese design for Under Water Concrete. It is possible to measure different properties such as filling ability, passing ability and to some extent segregation with the L – box. The apparatus is as shown in Fig.4.3. The apparatus consists of a rectangular section box in the shape of L, with a vertical and horizontal section. Vertical reinforcement bars are placed at the intersection of the two areas of the apparatus. A moveable gate separates the two sections (vertical and horizontal). The vertical section is filled with concrete and then the gate lifted to allow the concrete flow into the horizontal section. When the flow has stopped, the height of the concrete (H2) at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H1). It indicates the slope of the concrete at rest. This is an indication of passing ability.

The horizontal section of the box can be marked at 200mm and 400mm from the gate and the times taken to reach these points measured. These are known as T_{20} and T_{40} times and are an indication for the filling ability.

Assessment of Test
This is a widely used test, suitable for laboratory and site use. It assesses filling ability, passing ability of SCC, and segregation is also detected visually.
Equipment

- L – box of a stiff non absorbing material
- Trowel
- Scoop
- Stopwatch
- Ruler

Procedure

- To perform this test about 14 litres of concrete is needed
- Apparatus should be kept on a firm ground and the sliding door is closed
- The inside surfaces of the apparatus are moistened
- The vertical section of the apparatus is filled with concrete and leave it to stand for 1 minute
- Sliding gate of the apparatus is lifted and the concrete is allowed to pass or flow out into the horizontal section
- Start the stop watch and the times taken for the concrete to reach the 200mm and 400mm distances are recorded
- The distances H1 and H2 are measured after the flow has been stopped
- The blocking ratio H2/H1 is calculated
- The whole test has to be performed within 5 minutes
Interpretation of Test Results

If the concrete flows as freely as water, at rest it will be horizontal, so $H_2/H_1$ i.e blocking ratio is equal to 1. Therefore the nearer this test value is to unity, the better is the flow of the concrete. According to EFNARC standards, typical acceptance criteria for SCC with a maximum aggregate size up to 20mm are shown in Table 4.3.

These typical requirements shown against each test method are based on current knowledge and practice. Values outside these ranges may be acceptable if the producer can demonstrate satisfactory performance in the specific conditions.

4.4 FRESH AND HARDENED PROPERTIES

4.4.1 Testing of SCC in Fresh State

To get properties such as filling ability, passing ability and segregation resistance by conducting Slump cone, V-funnel, and L-box tests SCC was tested in fresh state.
4.4.2 Casting of Specimens

After testing SCC for fresh properties, the mix was placed, filled in moulds, allowed to flow and settle itself in the moulds. Excess concrete was removed with trowel.

4.4.3 Curing of Specimens

The specimens were left in the moulds undisturbed at room temperature for about 48 hours after casting. The specimens after removing from the moulds were immediately transferred to curing ponds containing clean and fresh potable water.

4.4.4 Testing of Specimens in Hardened State

The specimens which were cast at standard conditions were tested as per standard testing procedures. After the specimens were taken out from the curing tank their surfaces were wiped off and tested as per IS 516-1959. For testing of specimens a time schedule was maintained to ensure their proper testing on the due date and time.

4.4.4.1 Compression Test

Generally the maximum size of coarse aggregate used is of 20 mm, and cubes of 150 X 150 X 150 mm are used to determine compressive strength of concrete. But in this investigation maximum size of aggregate used was only 10mm; hence cubes of smaller size 100 x 100 x 100 mm were used to find the compressive strength of the mixes. The specimens were tested in accordance with IS 516-1959. Testing was done on a 1000 kN capacity compression testing machine by the following procedure.
The specimens were taken out of the curing tank after the required period of curing, wiped off the moisture to make the specimens’ surface dry. Later it was placed on the compression testing machine (CTM) in such a way that its face perpendicular to the direction of compaction was on the bearing surfaces and load was applied centrally. The load was applied at the uniform rate of 140 kg/sq.cm per minute until specimens are failed. The maximum load at which failure occurred was noted. The test was repeated for three specimens and the average value was taken as the mean strength. Test set up is given in plate 1.4.

### 4.4.4.2 Split Tension Test

The test was carried out by placing a cylindrical specimen of diameter 150 mm and 300 mm long horizontally between the loading surfaces of a compression testing machine and load was applied until failure of the specimen. When the load was applied along the generatrix, an element on the vertical diameter of the cylinder is subjected to a vertical compressive stress and horizontal stress.

The horizontal stress = $2P/\pi LD$ Where $P$- the compressive load on the cylinder, $L$-length and $D$-diameter of the cylinder.

In order to reduce the magnitude of high compressive stress near the points of application of the load, narrow packing strips of suitable material such as ply wood are placed between the specimen and the loading platens of the testing machine. The test set up measuring split tensile strength is given in plate 1.5.
4.4.4.3 Flexure Test

The flexural strength of concrete is determined by subjecting a plain concrete beam to flexure under transverse loads. The theoretical maximum tensile stress reached in the bottom fibre of a standard test beam is often referred to as the modulus of rupture, the magnitude of which depends on the dimensions of the beam and the type of loading. IS 516 – 1959 specifies two point loading. The details of specimen and testing procedure are as follows.

The specimens of 100 x 100 x 500 mm were cast and used for testing under two point load to determine the flexural strength of SCC mixes. The specimen was placed in the flexural testing machine in such a manner that the load was applied to the upper most surface as cast in the mould. Load was applied without shock and was increased gradually at a rate such that the extreme fibre stress increases at approximately 0.70 kg/sq.cm/min, i.e. at 180 kg/min for 100 mm specimens. The load was increased until the specimen failed and maximum load at which failure occurred was recorded.

The flexural strength of concrete was calculated using the formula

\[ f_{cr} = \frac{PL}{bd^2}, f_{cr} = \frac{3Pa}{bd^2} \] when \( a > 110 \) mm but \( < 133 \) mm for 100 mm size specimens, If \( a < \) than 110 mm the test results are discarded.

Where \( P \)-maximum load at failure point (N), \( b \)-width & \( d \)-depth of specimen at the point of failure (mm)

\( L \)- length of span on which the specimen was supported (mm)

\( a \) - the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen.
4.4.5 Mix Proportions with Different Mineral Admixtures and their Combinations

GGBS Mix

The mix proportion was designed based on EFNARC method of mix design, using GGBS as filler material. Different trial mixes were attempted in the laboratory to get a GGBS SCC mix, which gives required fresh and hardened properties.

Replacement of Rice Husk Ash (RHA) to the Optimized Mix Proportions

Rice husk ash was used as replacement for GGBS in small quantities to the above optimized GGBS mix without violating the properties of SCC in fresh state and their hardened properties like Compressive strength, Tensile strength and Flexural strength were studied. From the results the mixes which have satisfied the fresh and hardened properties were taken for further investigations.

4.4.5.1 Selection of Final SCC Mix Proportions

Finally eight SCC mix proportions, with mineral admixtures GGBS and RHA which had satisfied properties of SCC in fresh state and also had shown relatively high compressive strengths were selected and taken for further investigations.

4.5. EVALUATION OF STRENGTH EFFICIENCY FACTORS

The present investigation is an effort to quantify the 3, 7 and 28-day cementitious efficiency of Ground Granulated Blast Furnace Slag (GGBS) and Rice Husk Ash (RHA) in SCC at various replacement levels. It was observed that this overall strength efficiency of GGBS
concretes was found to be a combination of general efficiency factor (depending on the age) and a percentage efficiency factor (depending upon the percentage of replacement). This evaluation makes it possible to design GGBS-SCC for a desired strength at any given percentage of replacement.

In this study, the behavior of GGBS in concrete has been studied by evaluating the efficiency of GGBS at different percentages of replacement at 3, 7 and 28 days. This is achieved by evaluating overall efficiency factor “k” for GGBS with different replacement dosages at 3, 7, 28-day compressive strength on M20, M40 and M60 SCC mixes.

4.6. STUDIES ON STRESS-STRAIN BEHAVIOUR OF SCC MIXES WITH GGBS AND RHA

In the fourth phase of investigation the stress-stain behavior of SCC with GGBS and RHA, with and without steel were studied. A total number of one hundred and forty four cylinders were cast without steel and with different percentages of steel and tested. The test was carried out on cylindrical specimens of diameter 150 mm and height 300 mm. After casting the specimens they were cured for 28 days in curing tank, then the specimens were wiped off the moisture and made surface dry. The cylinder was placed in a computer controlled universal testing machine (UTM) of 1000 kN capacity such that load was applied centrally. The specimens were tested under strain control uni-axial compression as per IS 516:1959 to get the stress-strain
characteristics. The test set up is shown in plate no.1.6. From these values the stress-strain curves for different SCC mixes were determined.

After obtaining the stress-strain behaviour of SCC mixes experimentally, empirical equations were developed to represent uni-axial stress-strain behaviour of SCC with GGBS and RHA, with and without steel confinement. From these empirical equations, theoretical stresses were calculated and compared with experimental values.

4.7 STUDIES ON FLEXURAL BEHAVIOUR OF SCC MIXES

In the fifth phase of investigation sixteen simply supported beams consisting of eight under reinforced and eight over reinforced beams were cast and tested under third point loading and its load-deflection, moment curvature behaviour along with crack widths, load at first crack, ultimate load carrying capacities, and crack pattern for under reinforced, over reinforced beams were investigated. Theoretically the Moment-Curvature relationships were developed using theoretical stress-strain relationships of concrete and steel. This is explained in detail below.

4.7.1. Flexural Behaviour of Self Compacting Concrete Beams with GGBS and RHA.

To study the flexural behaviour of self compacting concrete, under reinforced and over reinforced beams were cast and tested under third point loading and their behaviour in flexure was investigated.
Under and over-reinforced beams of size 100 x 150 x 1200 mm were cast with eight SCC mix proportions, with and without admixtures. Based on limit state method, the reinforcement required for balanced section was calculated first and then the amount of reinforcement for under and over reinforced was determined. In M20 mix for under reinforced beams 2-8 mm dia. Steel bars was provided in tension side and for over reinforced beams 2-12 mm dia steel bars was provided in tension side along with 2 hanger bars of 6 mm dia to support the 6 mm diameter 2-legged mild steel vertical stirrups at 90 mm center to center.

In M40 mix, for under reinforced beams 2-12mm dia steel bars are provided and for over reinforced beams 2-16 mm dia steel bars are provided and finally in M60 mix 2-12mm dia steel bars are provided for under reinforced and 2-16mm dia steel bars for over reinforced beams. The reinforcement details are shown in plate 1.8. The calculation details of reinforcement are given in Appendix II

4.7.2. Preparation of Specimen for Testing

One day before the testing, the cured beams were white washed and the location of supports, load points, the position where the curvature meter frames and the deflection gauges have to be placed during the test were marked with the pencil.

4.7.3. Testing Procedure

The beams were tested under symmetrical two points loading on simply supported span of 1000 mm. The beam was placed on two roller supports, resting on cast iron blocks, placed on the wing table of
the Universal testing machine. The load was from the fixed cross head of the machine as two point loading, on the two rollers placed 333mm apart, by a loading beam of sufficient stiffness. Testing was performed under third point loading under controlled deflection. The crack propagation was carefully marked with the pencil. The test was continued until the load has fallen to 0.85 times the ultimate load observed. At that stage the testing was stopped by gradually releasing the outlet valve. The test was conducted as per I.S.516-1959. The test set-up is shown in plate 1.10

4.7.4 Measurement of Curvature

Specially fabricated curvature meters were used to measure the curvatures in the central zone. These curvature meters consist of four rectangular frames made out of a 12mm mild steel bar. Each frame can be fixed to the beam by means of two screws of 6mm diameter on either side of the beam. Two dial gauges of 0.002mm least count and 12mm travel were fixed between the two successive rectangular frames, one at the top and the other at the bottom. The deformations indicated by the dial gauges divided by the gauge length of 200mm give the strains at the level. From the top and bottom strains, the average curvatures were calculated.

4.7.5 Measurement of Deflections

Deflections were measured at five different points including the central point using the deflection meters. After obtaining the values of moments and curvatures experimentally, the same are calculated theoretically using the theoretical stress-strain relations of SCC.
These values are compared with experimental values and the variations are explained in detail in the discussions in chapter VIII.

4.8 DURABILITY STUDIES ON LOW, MEDIUM AND HIGH GRADE SCC BLENDED WITH GGBS AND RICE HUSK ASH

Self-compacting concrete cubes of 100 mm x 100 mm size which are cast with eight selected mixes of concrete and which are tested for compressive strength at the age of 28 days are taken for durability studies. The durability studies are done on cubes immersed in H$_2$SO$_4$, Na$_2$SO$_4$ & HCl for 30 days, 45 days, 60 days, 75 days and 90 days. The obtained results are presented in tables and the test results are also presented in the form of curves, for better study and analysis.

4.8.1 Acid attack After 28 days of curing, each cube is tested for weight and lengths. The cubes are subjected to 5% solutions of Sulphuric Acid (H$_2$SO$_4$), Sodium Sulphate (Na$_2$SO$_4$) and Hydrochloric acids (HCl) individually. Cubes are continuously immersed in solution for 30 days, 45 days, 60 days, 75 days and 90 days. The Acid Durability Factors, Acid Attack Factors, Weight Loss, and Compressive strength loss are studied.