Experimental Studies on Self Compacting Concrete with Partial Replacement of Fly Ash and Silica Fume

B. Chandana, M. Durga Rao

Abstract: ***The aim of this study is to evaluate the performance of Fly Ash and Silica Fume (replacement) a mineral admixture in concrete when it is mixed in cement concrete for workability, durability and strength of concrete using OPC (53- grade). Concrete over the past few years suggest that cement replacement materials along with mineral & chemical admixtures can improve the strength, workability and durability characteristics of concrete. The research has focused on developing self-compacting concrete in cooperating relatively large amounts of mineral by products such as Silica Fume and Fly Ash as supplementary cementing materials. This study investigates the performance of concrete mixture in terms of Compressive strength and split tensile strength for 7, 14 and 28 days respectively of M-30 grade concrete. This project deals with the self- compacting concrete where the replacement levels of OPC by Fly Ash were 15%, 20% and 25%, where replacement levels of OPC by Silica Fume were 6%, 9% and 12% by weight. Here in this project 1.2% of super-plasticizer was used in all the test specimens for better workability at lower water binder ratio and to identify the sharp effects of Silica Fume and Fly Ash on the properties of concrete. These Concrete specimens were deep cured in water under normal atmospheric temperature.***

Keywords: Self Compacting Concrete, Fly ash, Silica fume, Fresh Concrete Properties, Hardened Properties, Compressive Strength, Split tensile Strength.

I. INTRODUCTION

Concrete is a most widely used construction material in the world .As the use of concrete becomes almost a necessary the specifications of concrete like durability, quality, workability and compactness of concrete becomes more important. Conventional concrete is cast normally in the form of vibration in order to move the concrete to all corner of the form work, removes entrapped air, and to fully surround the reinforcement. With the introduction of the latest generation of super plasticizing admixtures it became possible to produce concrete that does not require mechanical vibration, thus leading us lo so called *Self-Compacting Concrete (SCC).*

A. Self-Compacting Concrete

Self-compacting concrete is a flowing concrete mixture that is able to consolidate under its own weight. Self-Compacting Concrete (SCC) is one of the special type of concrete which describes as "the most advanced development in concrete construction for several years ". At first it is initially developed because of the less skilled labor, This SCC has proved beneficially and economically because of some factors. The requirement led to the development of SCC and its development was first reported in 1989. Self-Compacting Concrete is also a type of high performance concrete that has high workability and Self-Compacting nature, i.e. the compaction occurs because of high flowing nature and there is need for external vibrators for compacting purpose. The concrete is cohesive enough to escape bleeding or segregation. For production of Self-compacting in order to achieve the water cement ratio should be kept as much as the minimum, but to increase the flowing property and high workability chemical admixtures are used.

Sustainable industrial growth will influence the cement and concrete industry in many aspects, as the construction industry has environmental impact due to high consumption of energy, which results in increase liberation of carbon dioxide (CO2). Thus, by partially replacing Cement by mineral admixtures such as Fly ash and Silica fumes, an effort is being made to reduce the global warning, and also these mineral admixtures are usually the industrial waste, by blending them with cement, these materials can be safely disposed.

The mix proportioning of SCC is carefully done. The aggregate content is smaller than conventional concrete that requires vibrating compaction. The method for achieving Self-Compatibility involves not only high deformability of paste or mortar, but also Homogeneity of SCC which is its ability to remain un-segregated during transportation and placing.

The main reasons for the development of SCC can be summarized as follows:

1. To shorten construction period.
2. To assure compaction in the structure.
3. To eliminate noise due to vibration.

B. Requirements for SCC

SCC must possess the following three characteristics to meet its stated workability requirements:

i. Filling Ability

The ability of SCC should fill the spaces completely within the formwork under its self - weight.

ii. Passing Ability

The ability of SCC should flow through tight openings such as between the reinforcing bars without segregation and bleeding. The ability of SCC should remain homogeneous during transportation and placing.

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B. Chandana, PG Scholar Department of Structural Engineering, Gudlavalleru Engineering College, Gudlavalleru (A.P), India.

M. Durga Rao, Assistant Professor, Department of Civil Engineering, Gudlavalleru Engineering College, Gudlavalleru (A.P), India.

C. Benefits of SCC

The technologically advanced components of SCC work together to create a mix that produces numerous benefits. It offers many advantages, some of them are as stated.

- Reduces the vibration effort and noise during placing of concrete.
- Ability to fill complex forms which has limited access.
- Uniform distribution of concrete in areas of closely placed reinforcement bars.
- Rapid pumping of concrete.
- Reduces the surface voids and requirement for rubbing and patching.
- Improves aesthetics of work for less effort.
- Reduced labor and construction time.
- Best use of mixing equipment and delivery.

D. Limitations of SCC

The production of SCC places more dependent on the selection of materials in comparison with conventional concrete, it offers many disadvantages, some of them are as stated.

- A slight change in the characteristics of a SCC mixture could be a warning sign for quality control.
- An uncontrolled variation of even 1% moisture content in the fine aggregate will have a much bigger impact on the rheology of SCC at very low W/C (~0.3) ratio.
- The development of a SCC requires a large number of a trial batches. Once a good mix has been prepared, further trial batches are required to quantify the characteristics of the mixture.
- SCC is costlier than the conventionally used concrete initially based on concrete materials cost due to higher dosage of chemical admixtures.

II. OBJECTIVE OF THE STUDY

- To study the effect of Fly Ash and Silica Fume in the properties of Self compacting Concrete (SCC).
- To find the optimum replacement levels of Fly Ash and Silica Fume in Self Compacting Concrete (SCC)
- To determine the percentage growth rate in hardened properties like compressive strength, split tensile strength.
- To study the fresh and hardened properties (i.e., compressive strength, split tensile strength) with partial replacement of cement by Fly Ash in three different percentages such as 15%, 20%, 25% and Silica Fume in three different percentages such as 6%, 9%, 12% are evaluated.

III. MATERIAL PROPERTIES

In this present work materials used are Cement, Fine Aggregate, Coarse Aggregate, Fly Ash, Silica Fume and Super Plasticizer.

A. Cement

KPC cement of Ordinary Portland Cement (OPC) of 53 Grade was used which full fills the requirements of IS 12269-1987. A few preliminary tests was conducted on the cement. The results was given in Table 1.

Table 1. Cement Test Results

Physical property	Value of OPC used	As per IS 12269-1987
Standard consistency	31%	---
Initial setting time	33mins	Maximum of 30 minutes
Final setting time	11hours	Maximum of 600 minutes
Specific gravity	3.15	----

B. Aggregates

i. Fine Aggregate:

Locally available sand passing through IS 4.75mm sieve is used which was conforming to Zone II as per IS 383-1987. The properties of sand was given in Table 2.

Table 2. Properties of F.A

Physical property	Values
Specific gravity	2.605
Fineness modulus	2.68
Grading Zone	Zone II

ii. Coarse Aggregate:

Locally available crushed aggregate of 12.5mm maximum size and retained on IS 4.75mm sieve has been used. It was tested as per IS 2386 - 1963. The properties of aggregates was given in Table 3.

Table 3. Properties of C.A

Physical property	Values
Aggregate size	12.5mm
Specific gravity	2.884
Water absorption	0.67%

C. Mineral Admixtures

i. Fly Ash:

Fly Ash is also known as pulverized-fuel ash, it is the ash precipitated electro-statically from the exhaust fumes of coal fired power stations, and is the most common pozzolana. In this the Class F fly ash used is obtained from Vijayawada Thermal Power Station in Kondapalli, Krishna (Dist.). In this experimental work class F fly ash is used.

The Chemical properties of class f fly ash is given in Table 4.

Table 4. Properties of Class F Fly Ash

Sl. No	Constituents	Percentage
1.	SiO_2+Al_2O_3+FeO_3	94.25
2.	Sulphur trioxide as SO_3	0.71
3.	Sodium oxide as Na_2O	0.26

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4.	Loss of ignition	0.38
5.	Silica as SiO_2	59.90
6.	Alumina as Al_2O_3	30.81
7.	Iron as Fe_2O_3	3.83
8.	Reactive SiO_2	30.01
9.	Calcium oxide as Cao	1.94
10.	Free Cao	Nil
11.	Reactive Cao	1.44
12.	Chloride as Cl	0.009
13.	Magnesium oxide as MgO	0.36
14.	Magnesium dioxide as MnO_2 (mg/Kg)	12.38
15.	Potassium oxide as $K_2OP_2O_5$ (mg/Kg)	0.031

Chemical Component	Class F fly ash
Silica (SiO2)	55
Alumina (Al_2O_3)	26
Ferric oxide (Fe_2O_3)	7
Calcium oxide (Cao)	9
Magnesium oxide (MgO)	2
Sulfate oxide (SO_3)	1
Loss of ignition (LOI)	6

ii. Silica Fume:

Silica fume is also known as condensed silica fume or micro silica and it is very fine. It is a specially processed product and is based on the slag of high glass content with high reactivity obtained through the process of controlled granulation. Silica fume is also finer than OPC in concrete and is owing to its unique chemistry and ultra-fine particle size, it has low absorption and denser packing features (Smaller particles of silica fume nestling between the OPC grains). It is typically an off-white colour. It also has the combination of physical and chemical properties of silica fume granules.

In this experimental work the mineral admixture used is silica fume, the physical properties of silica fume are given in Table5.

Table 5. Properties of Silica Fume

Physical property	Values
Specific gravity	2.25

D. Chemical Admixtures

i. Super Plasticizer – Conplast SP430

Conplast Sp430 is an admixture. It is used as a super plasticizer and is based on sulphonated naphthalene polymers and supplies as brown liquid instantly dispersible in water. It has been specially formulated to give high water reduction to produce high quality concrete of reduced permeability. Volume of Conplast used in this project is 1.2% of volume of the cement.

Table 6. Properties of Conplast SP430

Physical property	Values
Specific gravity	1.20 to 1.21 at 30^0 C
Chloride content	Nil. IS:9103-1999 and BS:5075
Air entertainment	Approx. 1.5% additional air over content

IV. METHODOLOGY

This experimental investigation is carried out to study the properties of SCC, with partially replacing different levels of fly ash and silica fume. To achieve optimum level of SCC, various trail mixes are done by varying cement, fine aggregate, coarse aggregate, water and super plasticizer. Once getting the Optimum Mix design with total nine mixes are done by replacing cement with fly at three different percentages 15, 20 and 25 silica fume added in percentages by mass of cement at 6%, 9% and 12%.

Experimental program is carried out in two phases. In *First phase*, each mix tests are conducted to assess the fresh workability properties i.e. (Slump flow, L-box, J-ring, V-funnel, U-box tests) of concrete.

In *second phase,* the fresh concrete are casted in cubes and cylinders. The specimens are cured in water for 7, 14, 28 days, these are tested for Mechanical properties i.e. (compressive strength and split tensile strength). Further the durability properties i.e. (Acid test) are conducted.

V. SCC MIX DESIGN

Design the traditional concrete mix with desirable compressive strength of 30 MPa. This involves the modifying the cement paste, or carefully tuning the aggregates, or both. As per the literature review the optimum level of fly ash is found to be 25% with combination of 6%, 9% and 12% of silica fume. So 25% of fly ash with 6%, 9% and 12% of silica fume is used in the traditional concrete mixes. This helps in comparing the optimum replacement level and % increment of compressive strength in traditional concrete as well as in self-compacting concrete.

A. Traditional Concrete Trail Mixes

Mix proportions M30 (1: 1.180: 2.132) CEMENT: F.A: C.A: W

550: 649.37: 1172.972: 165

1 : 1.180: 2.132

B. SCC EFNARC Guidelines

To adjust the designed trail mixes in SCC mix EFNARC gives few requirements. They are:

1. Water/Powder ratio by volume of 0.80 to 1.10
2. Total powder content of 160-240 liters (400-600 Kg) per cubic meter.
3. Coarse aggregate content normally 28-35% by volume of the mix.

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4. Water cement ratio is selected based on requirements in EN 206. Typically water content does not exceed 200 liter/m^3.
5. The sand content balances the volume of the other constituents.

VI. EXPERIMENTAL PROGRAM

The quantity of cement, fine aggregate, coarse aggregate, water and super plasticizer for each batch of mix proportions is prepared.

A. Properties of Fresh Concrete for SCC:

The main characteristics of SCC is its properties in fresh state. Mainly the SCC MIX design is focused on flowing ability under its own weight without any vibrations. The ability to flow through congested reinforcing bars under its own weight and also the ability to maintain the homogeneity without segregation of aggregates.

VII. FRESH STATE TESTS OF SCC

A. Slump Flow Test & T50:

Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work.
This test is used to find the filling ability of SCC. The SCC sample is poured into the cone then the slump diameter is measured. The flow time is measured and the concrete flows when the cone is withdrawn upwards the time for beginning upward movement of the cone to when the concrete has flowed to diameter of 500mm is calculated and that is known as T_{50} slump time. The higher the slump flow value, the greater its ability to fill form work under its own weight.
The apparatus for conducting the slump flow test essentially consists of a metallic moulds in the form of a cone having the internal dimensions as under and a sheet of 900mmx900mm.

Bottom diameter	: 20cm
Top diameter	: 10cm
Height	: 30cm

Test procedure:

• Put the clean base plate in an even and level position.
• Put the cone in the Centre on the 200 mm circle of the base plate and put the weight disc on the top of the cone to keep it in place.
• Fill up the cone with the test sample from the bucket with no any additional compacting action such as tamping or vibrating. The extra concrete above the top of the cone should be strike off and any concrete remaining on the base plate should be separated.
• Ensure that the test surface is neither too wet nor too dried out. No dry area on the base plate is allowed and any excess of the water should be separated.
• After a little rest (no extra than 20s for cleaning and inspection the moist state of the test surface), lift up the cone at right angles to the base plate, in such a manner that the concrete is allowed to flow out freely with no obstruction from the cone, and start the stopwatch the moment the cone free contact with the base plate.
• Stop the stopwatch when the front of the concrete first meets (touches) the marked circle of diameter 50 cm. The stopwatch reading is recorded which is known as the T50 value. The test is completed when the concrete flow has stopped.
• Measure the leading largest dia of the flow spread, d_{max}, and the one at right angles to it, d_{perp}, using the ruler scale (reading to nearest 4 mm).

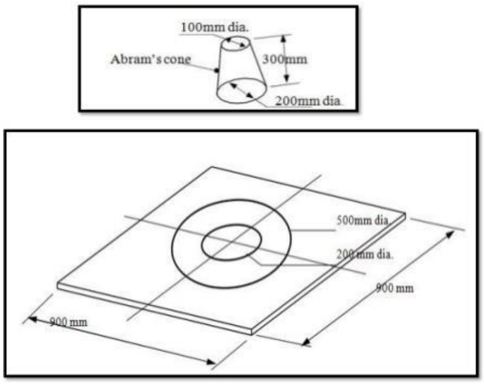

Figure 1. Slump Cone and 900 x 900 mm board

It is a test to assess the flow ability and the flow rate of SCC in the absence of obstructions. The result is an indication of the filling ability of SCC.

B. V-Funnel Test RT

The V-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum size of aggregate 20mm size. The funnel is filled with about 12 litre of concrete. Find the time taken for it to flow down.

After this funnel can be filled with concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

Equipment:

- V-funnel
- Bucket 12 litres
- Trowel
- Scoop
- Stopwatch

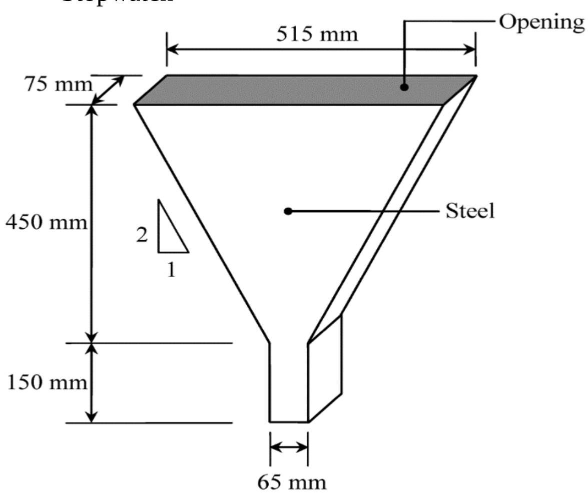

Figure 2. V- Funnel Apparatus

Procedure:

About 12 liters of concrete is needed for the test. Set the V-funnel on the firm ground.

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Moisten inside of the funnel. Keep the trap door open to remove any surplus water. Close the trap door and place a bucket underneath. Fill the apparatus completely with concrete no compaction or tamping is done. Strike off the concrete level. Open within 10 seconds the trap door and record the time taken for the concrete to flow down. Record the time for emptying. This can be judge when the light is seen when viewed from top. The whole test is performed within 5 minutes.

C. L-Box test

This test assesses the flow of concrete, and also the extent to which the concrete is subjected to blocking by reinforcement.

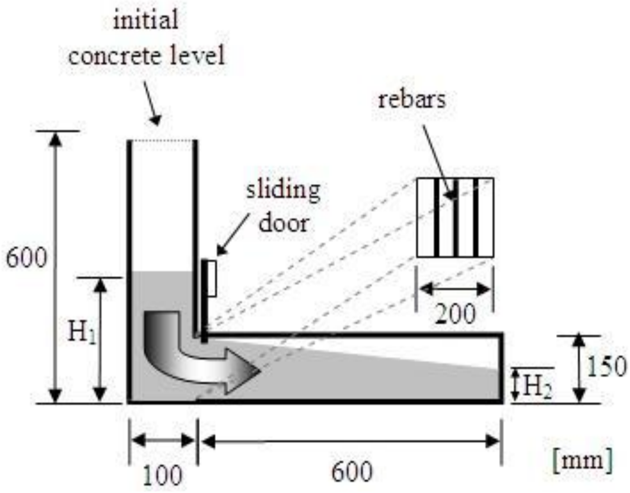

Figure 3. L-Box Apparatus

Procedure:

About 14 liters of concrete is required for this test. Ensure that the sliding gate can be open freely and then close it. Moisten the inside surface, remove all surplus water. Fill the vertical section of the apparatus with concrete. Leave it standing for 1 minute. Lift the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously start the stop watch and record the time taken for the concrete to reach 200 and 400 mm marks. When the concrete stops flowing, the height H2/H1 is the blocking ratio. The whole test has to be performed within 5 minutes.

Passing ability = H2/H1

The Passing ability value should be lies between 0.8 to 1

Recommended values as per EFNARC

Sl. No	Test	Permissible Values	
		Min	Max
1	Slump Flow	650	800
2	T_{50} Slump Flow	2 sec	5 sec
3	V-Funnel	6 sec	12 sec
4	U-Box (H_2/H_1)	0 mm	30 mm
5	J-Ring	0 mm	10 mm
6	L-Box (H_2/H_1)	0.8 mm	1.0 mm

VIII. CASTING OF SPECIMENS:

The concrete mix is casted into respective moulds. All the specimens were prepared according to Indian standards IS 516: 1959. After casting the specimens of cubes and cylinders are kept in water for curing.

A. Curing of Specimens

After the completion of rest of the time. The specimens were demoulded and the cubes, cylinders Specimens are cured in water for 7, 14 and 28 days.

B. Mechanical Properties

To determine the Mechanical properties of concrete SCC mix are subjected to various tests.

- Compression test
- Split tensile test

IX. RESULTS AND DISCUSSION

- **Fresh Properties**

Table 7. Workability Results

Mix Proportions	**Slump Flow Test *dia (mm)***	**V- Funnel Test**		**U-Box Test**	**J-Ring Test**	**L-Box Test**
		T_0 (Sec)	*T_5 (Sec)*			
Mix 1 (15% Fly ash + 6% Silica fumes)	685	8	9	3	4	0.86
Mix 2 (15% Fly ash + 9% Silica fumes)	683	9	9	3	5	0.88
Mix 3(15% Fly ash + 12% Silica fumes)	686	8	9	4	5	0.87
Mix 4 20% Fly ash + 6% Silica fumes)	689	8	8	4	4	0.89
Mix 5(20% Fly ash + 9% Silica fumes)	692	9	9	4	6	0.90

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Mix6(20% Fly ash+ 12%Silica fumes)	688	8	8	6	5	0.89
Mix 7(25% Fly ash+6%Silica fumes)	695	10	11	8	9	0.90
Mix 8(25% Fly ash+9%Silica fumes)	686	8	9	7	7	0.88
Mix 9(25%Fly ash+12%Silica fumes)	682	8	8	6	8	0.89

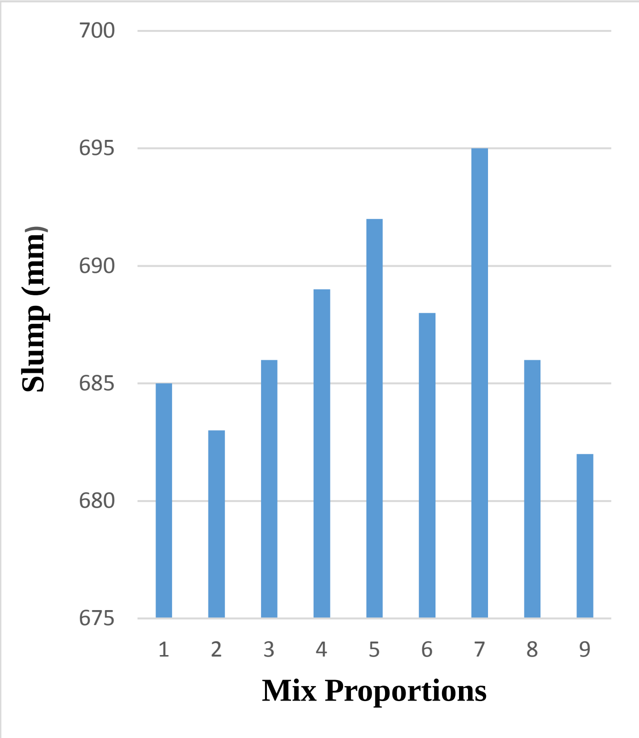

Chart 1. Slump Flow v/s Mix Proportions

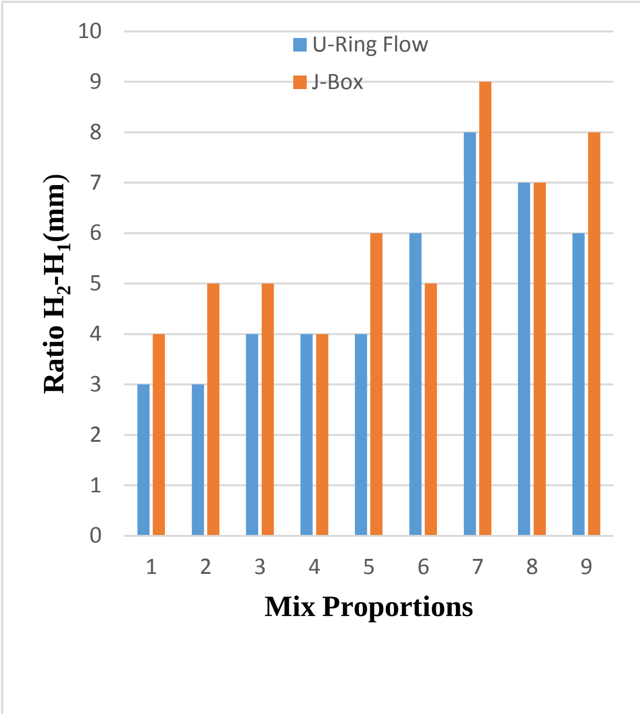

Chart 3. U-Ring Flow, J-Box Ratio v/s Mix Proportions

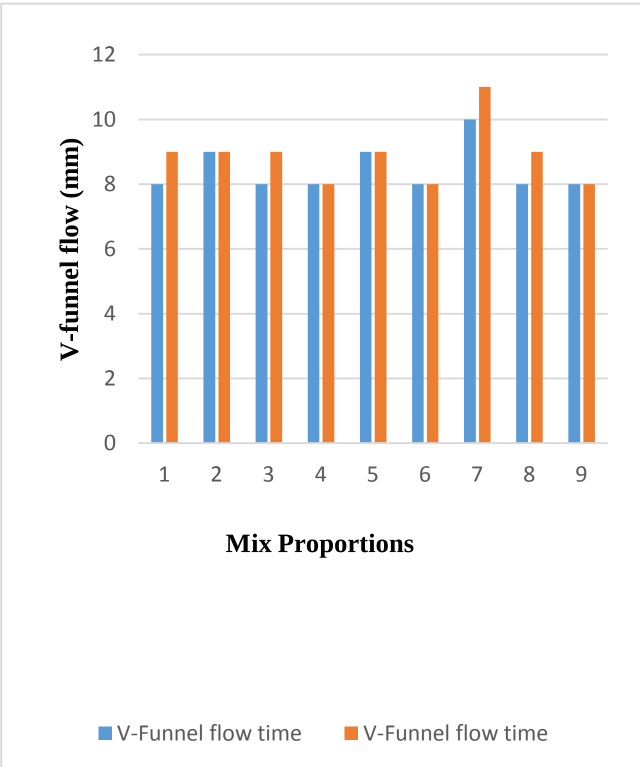

Chart 2: V-Funnel Flow Time v/s Mix Proportions

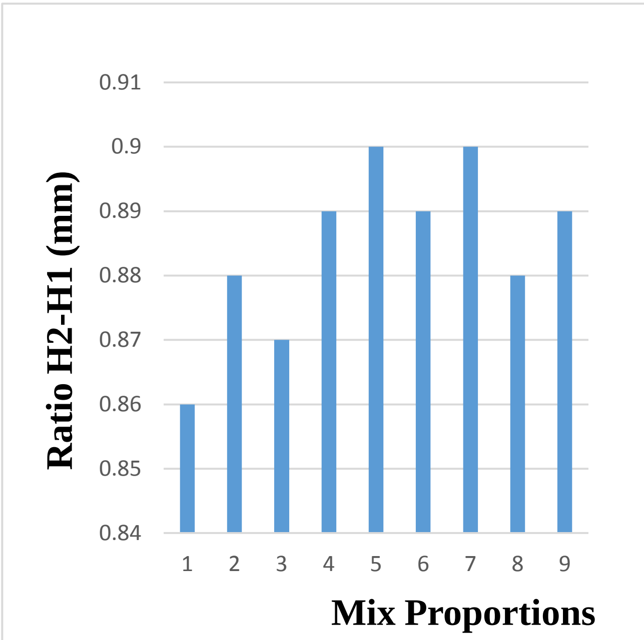

Chart 4: L-Box Ratio v/s Mix Proportions

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- **Mechanical Properties**

Table 8. Compressive Strength Results, Split Tensile Strength Results

Mix Proportions	Compressive Strength (N/mm^2)			Split tensile Strength (N/mm^2)		
	7 days	14days	28 days	7days	14 days	28 days
Mix 1(15% Fly ash + 6% Silica fumes)	16.12	18.57	24.58	2.38	2.91	3.02
Mix 2 (15% Fly ash + 9% Silica fumes)	18.73	20.56	27.62	2.43	2.97	3.11
Mix3(15%Flyash+ 12%Silica fumes)	17.41	23.61	28.17	2.51	3.03	3.29
Mix 4(20%Fly ash+6%Silica fumes)	21.03	26.99	32.29	2.62	3.20	3.31
Mix 5(20%Fly ash+9%Silica fumes)	22.66	28.33	34.02	2.68	3.34	3.50
Mix6(20%Fly ash+ 12%Silica fumes)	23.52	29.16	35.88	2.76	3.41	3.61
Mix 7(25%Fly ash+6%Silica fumes)	27.77	32.71	39.67	2.89	3.56	3.71
Mix 8(25%Fly ash+9%Silica fumes)	25.20	30.11	36.52	2.71	3.49	3.63
Mix 9(25%Flyash+ 12% Silica fumes)	22.38	29.40	32.91	2.61	3.44	3.59

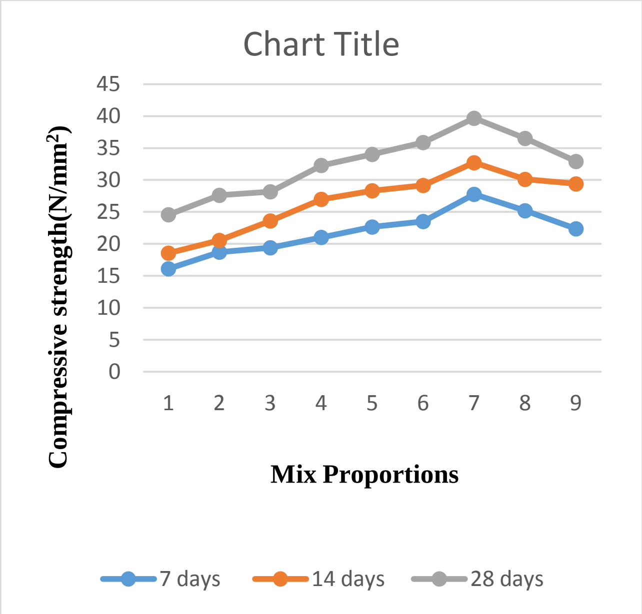

Chart 5: Compressive Strength Test Results

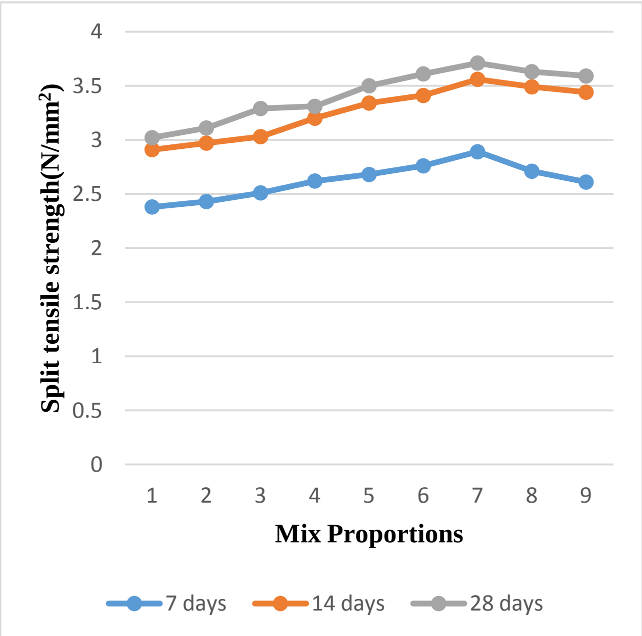

Chart 6: Split Tensile Strength Test Results

X. CONCLUSION

The following conclusions can be drawn from this study, based on the results obtained

- The percentage of Fly ash and Silica fumes in the mix will affects the Workability and Mechanical characteristics of SCC.
- All the nine mix are observed to be good workable mix, the results are all well within the EFNARC limits.
- Longer curing results in higher compressive strength. The compressive strength is more when the specimens is cured for 28 days.
- The compressive strength and split tensile strength is Maximum for 25% Fly ash + 6% Silica fumes.

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