Influence of Fly Ash and Silica Fumes on the Behavior of Self Compacting Concrete

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***Abstract* – Self Compacting Concrete (SCC) is one of the most significant advances in concrete technology in the last decades. SCC was mainly developed to ensure adequate compaction through self compaction and facilitate placement of concrete in structures with congested reinforcement and in restricted areas. SCC is a very fluid concrete and a homogenous mixture that solves most of the problems related to ordinary concrete. SCC gets compacted under its own weight and there is no need for an internal vibration for the body of the mould.**

An experimental investigation is carried out to study the properties of SCC, by partially replacing cement with certain percentage of Fly ash and Silica fume. Further, Workability, Mechanical & Durability properties are studied on these SCC mix proportions.

This paper presents the behaviour assessment of these SCC, and this shows promise as a greener substitute for Ordinary Portland Cement in some applications.

***Index Terms* - Self Compacting Concrete, Fly ash, Silica fumes, Workability, Mechanical and Durability properties.**

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 to so called *Self-Compacting Concrete (SCC).*

Self Compacting Concrete

Development of self compacting concrete (SCC) is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. SCC is not affected by the labour skills, the type of reinforcement bars or arrangement of a structure, and due to its high flowing ability and resistance to segregation it can be pumped longer distances.

SCC has been developed to ensure adequate compaction and facilitate placement of concrete in structures with congested reinforcement and in restricted places. SCC was developed first in Japan in the late 1980s to be mainly used for highly congested reinforced structures in seismic regions. As the durability of concrete structures became an important issue, an adequate compaction by skilled labours was required to obtain durable concrete structures.

The requirement led to the development of SCC and its development was first reported in 1989. SCC can be described as a high performance material which flows under its own weight without requiring vibrators to achieve consolidation by complete filling of formworks even when access is hindered by narrow gaps between reinforcements.

A 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 (CO_2). 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.

A. Requirements for SCC

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

- **Filling Ability**

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

- **Passing Ability**

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

- **Segregation Resistance**

  The ability of SCC should remain homogeneous during transportation and placing.

B. 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.

C. 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. Research Significance

This paper describes a procedure specifically developed to achieve SCC, using mineral admixture like Fly ash and Silica fumes, as a partial replacing material for cement. In addition, the test results for acceptance characteristics for SCC such as Workability characteristics (Slump flow, J-ring, V-funnel, U-box and L-Box), Mechanical characteristics (Compressive, Split Tensile, Flexural strength), Durability characteristics (Acid test) are presented.

III. Materials and Methodology

The Materials used in the research are:

1. Cement

Cement paste is the binder in SCC that holds the aggregate (coarse, fine, admixtures) together and reacts with mineral materials in hardened mass. The property of SCC depends on the quantities and the quality of its constituents. In this present work, *Ordinary Portland Cement of 53 grade Aditya Birla Super* conforming to IS: 12269-1987 has been used and tested for their properties, presented in Table 1.

Table 1: Properties of Cement

Sl No	Properties		Results	IS:12269 -1987
1	Standard Consistency		27%	---
2	Fineness % (retained on 90µ sieve)		3%	≤ 10%
3	Soundness (by Le Chatelier)		3 mm	≤ 10mm
4	Initial setting time (min)		62	≥ 30
5	Final setting time (min)		370	≤ 600
6	Specific gravity		2.95	---
7	Compressive Strength (N/mm^2)	7 days	45	≥ 37
		28 days	65	≥ 53

2. Fine Aggregate

In this investigation fine aggregate used is 4.75 mm down, manufactured sand from *RMC India Pvt. Ltd, Kumbalgud, Bangalore* are tested as per IS: 2386, presented in Table 2.

Table 2: Properties of Fine Aggregate

Sl No	Properties	Results
1	Type	Manufactured
2	Surface Texture	Crystalline
3	Specific Gravity	2.62
4	Water Absorption	4.5%
5	Moisture Content	1.6%
6	Fineness Modulus	3.43
7	Grading Zone	Zone II

3. Coarse Aggregate

Coarse aggregate crushed granite of 12.5 mm maximum size and retained on IS 4.75 sieve has been used, obtained from the *local market in Bangalore*, are tested as per IS: 2386, presented in Table 3.

Table 3: Properties of Coarse Aggregates

Sl No	Properties	Results
1	Surface Texture	Crystalline
2	Specific Gravity	2.70
3	Water Absorption	0.4%
4	Moisture content	0.2%
5	Bulk density	1.62
6	Fines Modules	6.78

4. Mineral Admixtures

a) Fly Ash

Fly ash, known also as pulverized–fuel ash, is the ash precipitated electro-statically from the exhaust fumes of coal-fired power stations, and is the most common artificial pozzolana.

In this investigation work, the fly ash used is obtained from *Kudathini, Bellary (Dist) Thermal Power Station in Karnataka*. Specific gravity is 2.08. Chemical composition is given in Table 4.

Table 4: Chemical composition of Fly Ash

Sl No	Parameter	Quantity (% wt)
1	Silicon Dioxide(SiO_2)	62.63
2	Alumina(Al_2O_3)	23.35
3	Iron oxide(Fe_2O_3)	3.93
4	Calcium oxide (CaO)	2.04
5	Magnesium oxide (MgO)	0.46
6	Sulfur tri oxide (SO_3)	1.34
7	Sodium oxide (Na_2O)	0.032
8	Potassium oxide (K_2O)	0.030
9	Loss On Ignition % by mass	0.39
10	Bulk density	1.11gm/cc

b) Silica Fumes

Silica fume is a byproduct resulting from the reduction of high-purity quartz with coal/coke in an electric arc furnace during the production of Silicon metal/Ferro-silicon alloys.

In this investigation work, the Silica fume used is obtained from *Corniche India Pvt. Ltd. Mumbai.* Specific gravity is 2.15. Chemical composition is given in Table 5.

Table 5: Chemical composition of Silica Fumes

Sl No	Parameter	Results	ASTM-C-1240
1	SiO_2	91.9%	Min 85%
2	Loss On Ignition	2.8%	Max 6%
3	Moisture	0.3 %	Max 3%
4	Pozz. Activity Index	133%	Min 105%
5	Bulk Density	601	550-700
6	Specific Surface Area	22 m^2/gm	Min 15 m^2/gm
7	+ 45 Microns	0.2%	Max 10%

5. Chemical Admixture

a) Super plasticizer - Master Glenium Sky 8233

Master Glenium Sky 8233 is an admixture of a new generation based on modified Polycarboxylic ether.

In this investigation, Super plasticizer used is obtained from *BASF Chemicals India Ltd, Bangalore*.

Table 6: Specifications of Master Glenium Sky 8233

Aspect	Light Brown liquid
Relative density	1.08 ± 0.01at 25˚c
pH	≥ 6
Chloride ion content	< 0.2%

6. Water

The water should be clean and free from harmful impurities. The analysis of water is shown in the Table 7**.**

Table 7: Test Results of Water

Sl No	Contents	Units
1	pH	7.72
2	Acidity	NIL
3	Specific conductance	835 micro/mhos
4	Total Hardness	274 mg/litre
5	Chloride	105 mg/litre
6	Sulphate	63 mg/litre
7	Calcium	109 mg/litre
8	Sodium	10 mg/litre
9	Alkalinity	260 mg/litre

Methodology

Experimental investigation is carried out to study the properties of SCC, by partially replacing cement with certain percentage of fly ash and silica fume. To achieve optimum SCC mix various trail mix are done by varying cement, coarse and fine aggregate, water and super plasticizer. Once getting the Optimum Mix Design, totally nine mixes are done by replacing cement with fly ash at 15, 20 and 25%, silica fume added in percentage by mass of cement at 6, 9 and 12 %.

Experimental programme are carried out in two phase. In the *First Phase*, for each mix tests are conducted to assess fresh Workability properties (Slump flow, J-ring, V-funnel time, L-box ratio and U-box test) of concrete.

In *Second Phase*, fresh concrete are cast into cubes, cylinders and beams. Specimens are cured in water till testing for 7, 28, 56, 90 days, than are tested for Mechanical properties (Compressive strength, Split Tensile strength, Flexural strength).

Further, Durability properties (Acid Test) are conducted.

IV. Mix Proportion

The portioning of the mix is extremely important in developing an effective SCC. This involves either modifying the cement paste, or carefully tuning the aggregates, or both.The interlocking of coarse aggregates is integral to the strength of the concrete.With coarse aggregate, changing interparticle spacing most practically changes the flowability of concrete.

The cement paste must work with the coarse aggregates to fill the interstitial voids for a given particle size distribution of aggregate and produce a desirable interparticle spacing.

Till date there is no specific code book for mix design of SCC, but EFNARC provides specification and guidelines.

EFNARC Specification and Guidelines for SCC-2002

- Water / Powder ratio by volume of 0.80-1.10
- Total powder content of 160-240 lts (400-600 Kg) per cubic meter.
- Coarse aggregate content normally 28-35% by volume of the mix.
- Typically water content does not exceed 200 lts/m^3.
- The sand content balance the volume of the other constituents.

V. Experimental Program

The quantity of Cement,Aggregates (Fine & Coarse), Mineral admixture (Fly ash & Silica fume), Water and Chemical admixture (super plasticizer) for each batch of proportion is prepared as mentioned in design of SCC.

- **Fresh Properties of SCC**

The main characteristic of SCC is its properties in the fresh state. SCC mix design is focused on the flowing ability, under its own weight without vibration. The ability to flow through congested reinforcing bars under its own weight. And, the ability to maintain the homogeneity without segregation of aggregates.

Table 8: Recommended values as per EFNARC

Sl No.	Test	Permissible Values	
		Min	Max
1	Slump Flow	650 mm	800 mm
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

i. Casting of Specimens

The mixed concrete is cast into respective moulds.All the specimens were prepared in accordance with IS516:1959. After casting, the specimen cubes, cylinder, beams are kept in water for ambient curing.

ii. Curing of Specimens

After completion of the rest period, the specimens were demoulded and the cubes, cylinder, beams specimens are allowed to get cured for 7, 28, 56 and 90 days.

- **Mechanical Properties of SCC**

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

1) **Compression Test**
2) **Split Tensile Test**
3) **Flexural Test**

- **Durability Properties of SCC**

To determine the Durability properties of concrete, SCC mix are subjected to various test.

1) Acid Test

Several test methods are available to evaluate these main characteristics of SCC. The tests used for evaluating the characteristics of fresh SCC in accordance with the *EFNARC Specification and Guidelines for Self Compacting Concrete 2002* are described below, in Table 8.

Mix Proportions	Cement Kg/m3	Fly Ash Kg/m^3	Silica Fume Kg/m^3	Fine Agg Kg/m^3	Coarse Agg Kg/m^3	Water Kg/m^3	Super Plas-0.8% Kg/m^3	W/P ratio	Density (kg/m^3)
Mix 1 (15% Fly ash + 6% Silica fumes)	441.21	59.07	24.42	879.73	714.42	189.32	4.198	0.361	2380
Mix 2 (15% Fly ash + 9% Silica fumes)	424.46	59.07	36.63	879.73	714.42	189.32	4.162	0.364	2415
Mix 3 (15% Fly ash + 12% Silica fumes)	407.70	59.07	48.84	879.73	714.42	189.32	4.125	0.367	2386
Mix 4 (20% Fly ash + 6% Silica fumes)	413.29	78.76	24.42	879.73	714.42	189.32	4.132	0.367	2450
Mix 5 (20% Fly ash + 9% Silica fumes)	396.53	78.76	36.63	879.73	714.42	189.32	4.096	0.370	2434
Mix 6 (20% Fly ash + 12% Silica fumes)	379.78	78.76	48.84	879.73	714.42	189.32	4.059	0.373	2468
Mix 7 (25% Fly ash + 6% Silica fumes)	385.36	98.45	24.42	879.73	714.42	189.32	4.066	0.373	2430
Mix 8 (25% Fly ash + 9% Silica fumes)	368.61	98.45	36.63	879.73	714.42	189.32	4.030	0.376	2386
Mix 9 (25% Fly ash + 12% Silica fumes)	351.85	98.45	48.84	879.73	714.42	189.32	3.994	0.379	2435

Table 9: Mix design for 1cc of Cement

VI. Results and Discussions

✓ **Fresh Properties**

Table 10: Workability Results

Mix Proportions	Slump Flow Test *Dia (mm)*	V-Funnel Test		U-Box Test *H_2-H_1 (mm)*	J-Ring Test *H_2-H_1 (mm)*	L-Box Test *H_2-H_1 (mm)*	PH	Temp (·c)
		T_0 (sec)	*T_5 (sec)*					
Mix 1	685	8	9	3	4	0.86	11.7	27.7
Mix 2	683	9	9	3	5	0.88	11.8	27.8
Mix 3	686	8	9	4	5	0.87	12.0	27.8
Mix 4	689	8	8	4	4	0.89	12.2	27.8
Mix 5	692	9	9	4	6	0.90	12.6	27.9
Mix 6	688	8	8	6	5	0.89	12.4	27.8
Mix 7	695	10	11	8	9	0.90	12.7	27.9
Mix 8	686	8	9	7	7	0.88	12.5	27.7
Mix 9	682	8	8	6	8	0.89	12.4	27.8

Chart 1: Slump Flow v/s Mix Proportions

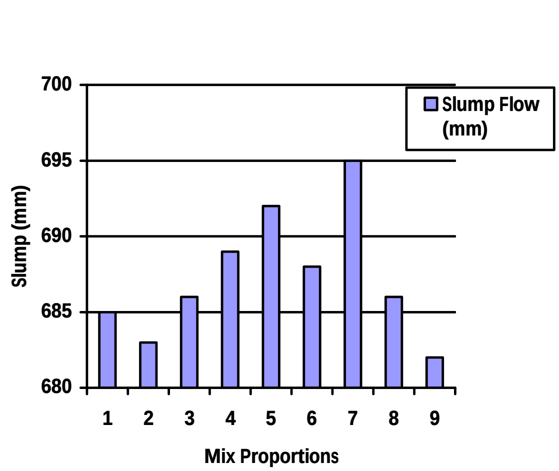


Chart 2: V-Funnel Flow Time v/s Mix Proportions

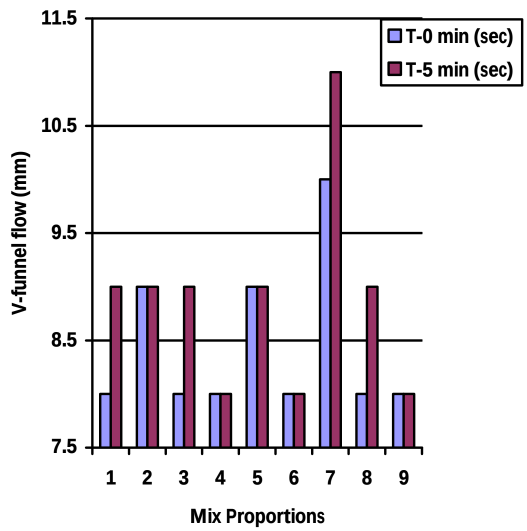


Chart 3: U-Ring Flow, J-Box Ratio v/s Mix Proportions

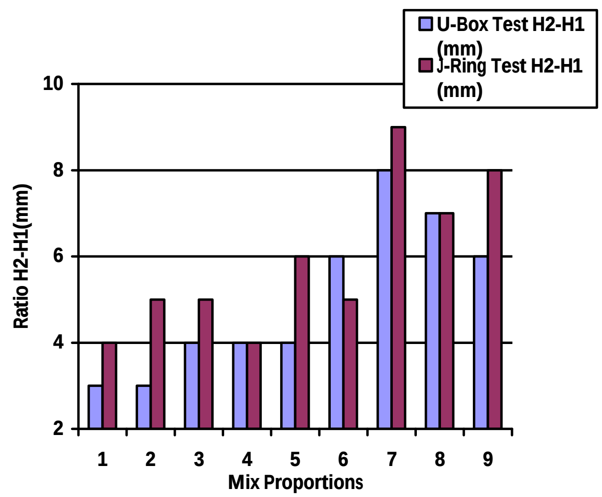
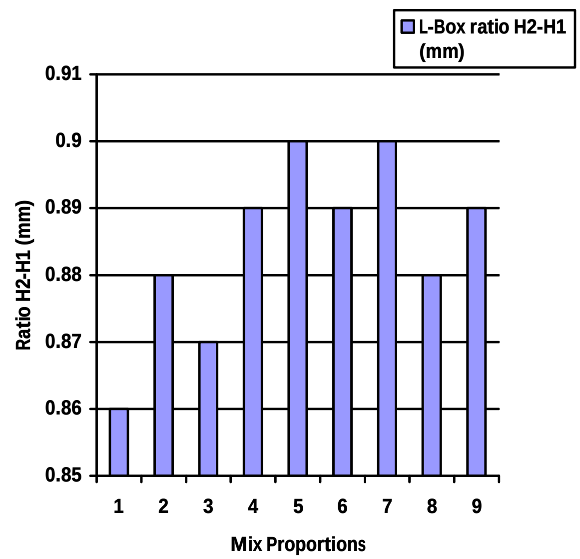


Chart 4: L-Box Ratio v/s Mix Proportions



✓ **Mechanical Properties**

Table 11: Compressive Strength Results, Split Tensile Strength Results, Flexural Strength Results

Mix Proportions	Compression Strength (N/mm^2)				Split Tensile Strength (N/mm^2)		Flexural Strength (N/mm^2)	
	7 days	28 days	56 days	90 days	28 days	56 days	28 days	56 days
Mix 1	39.6	55.31	59.79	63.56	4.31	4.46	11.8	12.6
Mix 2	41.76	58.05	63.87	67.20	4.38	4.49	12.0	13.0
Mix 3	42.37	59.91	65.60	69.68	4.42	4.63	12.3	13.5
Mix 4	44.64	62.93	66.76	72.10	4.62	4.82	12.7	13.8
Mix 5	45.36	63.02	67.36	70.38	4.75	4.87	12.9	14.0
Mix 6	46.68	65.77	70.64	74.87	4.85	4.95	13.1	14.3
Mix 7	49.68	69.40	74.68	77.21	4.96	5.06	13.5	14.7
Mix 8	47.52	66.34	70.52	74.08	4.77	4.91	13.2	14.4
Mix 9	45.36	63.36	67.10	70.21	4.59	4.72	13.0	14.1

Chart 5 : Compressive Strength Results

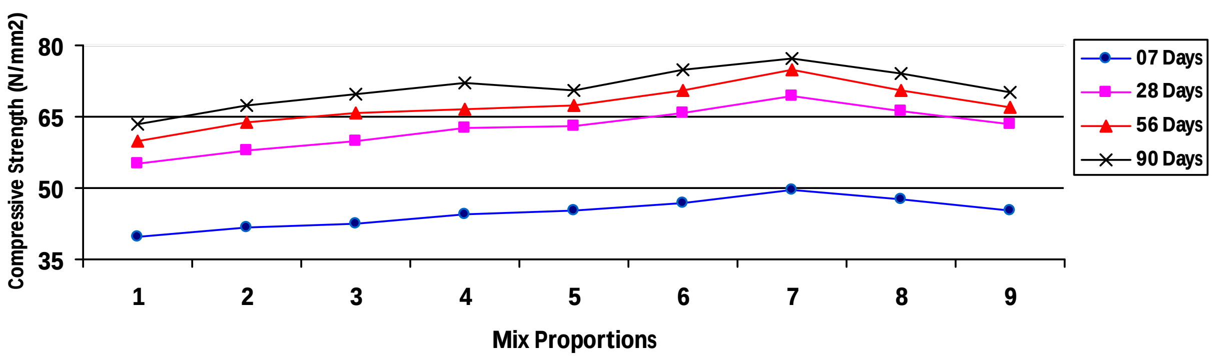


Chart 6 : Split Tenile Strength Test

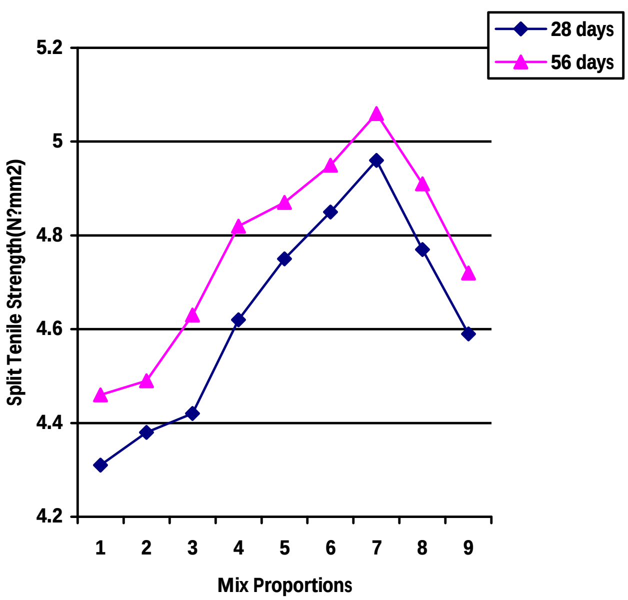
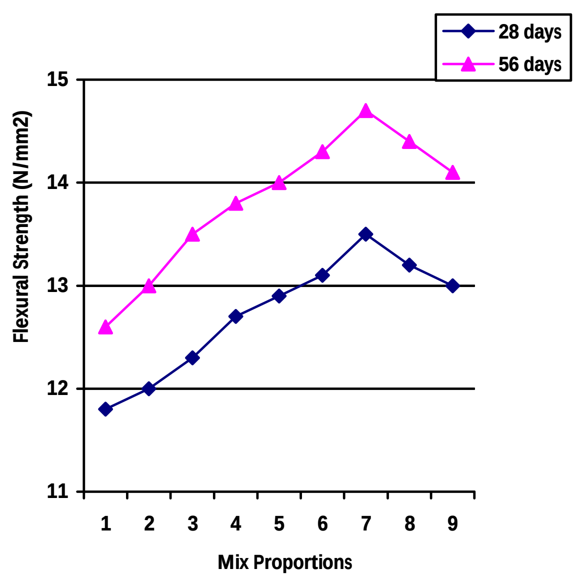


Chart 7 : Flexural Strength Test Results

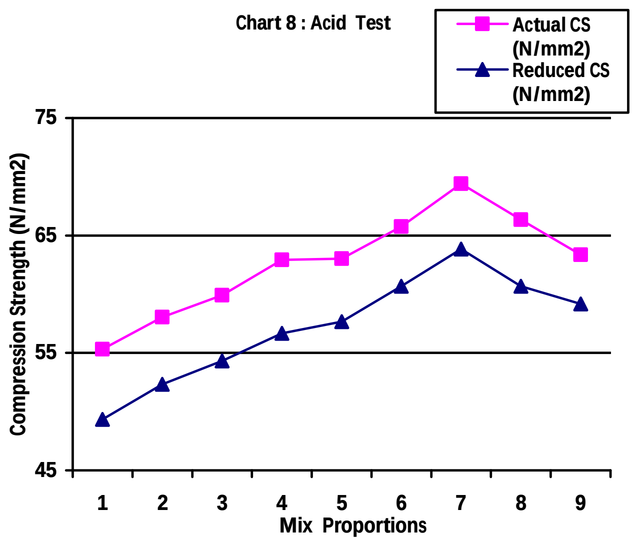


✓ **Durability Properties**

▪ **Acid Test**

Table 12: Acid Test Results

Mix Proportions	Weight (Kgs)		Compression Strength (N/mm^2)	
	Actual	Reduced	Actual	Reduced
Mix 1	2.514	2.486	55.31	49.33
Mix 2	2.452	2.426	58.05	52.33
Mix 3	2.560	2.540	59.91	54.33
Mix 4	2.448	2.428	62.93	56.67
Mix 5	2.456	2.438	63.02	57.67
Mix 6	2.490	2.462	65.77	60.67
Mix 7	2.380	2.254	69.40	63.83
Mix 8	2.472	2.438	66.34	60.67
Mix 9	2.416	2.404	63.36	59.17



VII. 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, Mechanical and Durability characteristics of SCC.
- All the nine mix are observed to be good workable mix, the results are all well within the EFNARC limits.
- The PH and Temperature Tests, helps us in better understanding of the Rheological characteristics of SCC.
- Longer curing duration results in higher compressive strength. The compressive strength is more when the specimens were cured for 90 days.
- The Compressive Strength, Split Tensile Strength & Flexural Strength is Maximum for mix proportion 25% Fly ash + 6% Silica fumes.
- The Acid Attack is at its peak for mix proportion 25% Fly ash + 6% Silica fumes

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