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Durability and Strength Properties on High Performance Self Compacting Concrete with GGBS and Silica Fumes

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ABSTRACT
This study on the experimental investigation on strength aspects like compressive strength, flexural strength and split tensile strength, and durability aspects like rapid chloride penetration test(RCPT) of high performance self-compacting concrete with different mineral admixtures . Initials tests like slump test, L-box test, U-box test and T50 test will be carried out. The methodology adopted here is Ground granulated blast furnace slag (GGBS) which is replaced partially by cement at 10%, 20% and 30% and silica fumes(SF) by 3%, 6%, 9% in combination with Portland cement and the performance is measured and compared. The influence of mineral admixtures on the workability, mechanical strength and durability aspects of self-compacting concrete are studied. The mix proportion is obtained as per the guidelines given by European Federation of producers and contractors of special products for structure.

Keywords:- Self-compacting concrete, Ground granulated blast furnace slag(GGBS), Silica fumes(SF), Workability.

I. INTRODUCTION

The development of High performance self-compacting concrete (SCC) has recently been one of the most important developments in the building industry. The purpose of this concrete concept is to decrease the risk due to the human factor, to enable the economic efficiency, more freedom to designers and constructors and more human work. It is a kind of concrete that can flow through and fill gaps of reinforcement and corners of moulds without any need for vibrations and compacting during the pouring process. Because of that, SCC must have sufficient paste volume and proper paste rheology. Paste volumes are usually higher than for conventionally placed concrete and typically consist of high powder contents and water-powder ratios.

There is no standard method for SCC mix design. Mix designs often use volume as a key parameter because of the importance of the need to over fill the voids between the aggregate particles. Some methods try to fit available constituents to an optimised grading envelope. Another method is to evaluate and optimise the flow and stability of first the paste and then the mortar fractions before the coarse aggregate is added and whole SCC mix tested. Conforming to EN 206-1: cement, additions (silica fume, ground granulated blast furnace slag), aggregate (limited to 20mm), admixture (Superplaticizer – Master Glenium Sky 8233) and water. This paper analyses characteristics and properties of mixtures with ground granulated blast furnace slag (GGBS) and silica fumes (SF).

II. RESEARCH SIGNIFICANCE

High performance self-compacting concrete (SCC) is a sensitive mix, strongly dependent on the composition and the characteristics of its constituents. It has to possess the incompatible properties of high flow ability together with high segregation resistance, a balance made possible by the dispersing effect of water-reducing admixture combined with cohesiveness produced by a high concentration of fine particles. The motive for the development of self-compacting concrete was the social problem on durability of concrete structures that arose around 1983 in Japan. Due to a gradual reduction in the number of skilled workers in Japan’s construction industry, a similar reduction in the quality of construction work took place. As a result of this fact, one solution for the achievement of durable concrete structures independent of the quality of the construction work was the employment of self-compacting concrete, which could be compacted into every corner of a formwork, purely by means of its own weight.

III. METHODOLOGY

The main aim of this work is to assess the feasibility of High performance self-compacting concrete with the mineral admixtures (GGBS and Silica fumes) replacing ordinary Portland cement by a known percentage to understand the change in properties of SCC. The Ordinary Portland cement is replaced by (GGBS10+SF3/6/9), (GGBS20+SF3/ 6/9), (GGBS30+SF3) percentage and super plasticizers is also added to get workability. Total seven mix designs are prepared and the properties are checked in fresh state and hardened state. And the test results are compared with reference to the literature survey. Fresh concrete are cast into cubes, cylinders and beams. The tests are conducted at 7,28,56,90 day curing for hardened concrete.

Rapid chloride penetration test (RCPT)is carried out on cubes which have passed 28 days of curing. The data on the resistance of the high performance self-compacting concrete mixture to chloride ion penetration is determined in accordance with ASTMC 1202 for the age of 28.

IV. MATERIALS AND PROPERTIES

The materials used in the research are:

4.1. Portland cement (53 grade)

In this work ordinary Portland cement of 53 grade conforming to IS: 12269-1987 has been used and tested for physical and chemical properties as per IS: 4031 – 1988 and found to be conforming to various specifications as per IS: 12269-1987.

TABLE-1 Properties of cement.

Sl No	Properties		Values	IS:12269-1987
1	Standard Consistency		27%	28%
2	Fineness % (retained on 90μ sieve)		3%	≤ 10%
3	Soundness (by Le Chatelier)		3 mm	≤10mm
4	Initial setting time (min)		62	≥30 min
5	Final setting time (min)		370	≤ 600 min
6	Specific gravity		2.95	-----
7	Compressive Strength	7 days	45	≤ 37 N/mm2
		28 days	65	≤ 53 N/mm2
8	Temperature during testing		27.8 °C	27° C ± 2°C

4.2. Fine aggregate

Manufactured sand obtained from a manufacturing plant at Kumbalgod area conforming to IS: 383-1997 is used as fine aggregate. The physical properties of fine aggregate are shown in table.

TABLE-2 Properties of fine aggregate

Sl No	Properties	Value
1	Specific gravity	2.62
2	Water Absorption	3.8%
3	Max size(mm)	4.7mm
4	Fineness modulus	3.6

4.3. Coarse aggregate

Coarse aggregate crushed granite of 12.5 mm maximum size and retained on IS 4.75 sieve has been used as coarse aggregate. The physical properties of coarse aggregate are shown in table.

TABLE-3 Properties of coarse aggregate

Sl No	Properties	Value
1	Specific gravity	2.7
2	Water Absorption	0.8%
3	Max size(mm)	20mm
4	Fineness modulus	6.5

4.4. Mineral admixtures

4.4.1 GGBS

Ground granulated blast-furnace slag is a non metallic product consisting essentially of silicates and aluminates of calcium and other bases. The molten slag is rapidly chilled by quenching in water to form glassy sand like material. The granulated material when further ground to less than 45 micron will have specific surface about 400 to 600m^2/kg. The chemical composition of blast furnace slag is similar to that of cement clinker.

In this investigation, GGBS is brought from steel work at Bellary. Specific gravity of GGBS is 2.62 and its chemical composition is shown in table.

TABLE-4 Chemical components of GGBS

Sl No	Parameter	Quantity (% wt)
1	Insoluble residue	0.83
2	Manganese Oxide	0.25
3	Magnesium oxide	10.13
4	Sulphide sulphur	0.75
5	$CaO+MgO+1/3Al_2O_3$ $SiO_2+2/3Al_2O_3$	1.10
6	$CaO+MgO+Al_2O_3$ SiO_2	1.84

4.4.2 Silica fumes

Silica fume is a highly efficient pozzolanic material and has considerable potential for use in concrete. Silica fume is obtained from Standard supplier at Mumbai. Specific gravity is 2.15.

TABLE-5 Components of silica fumes

Sl No	Parameter	Value	ASTM-C-1240
1	SiO2	91.9%	Min 85%
2	LOI	2.8%	Max 6%
3	Moisture	0.3 %	Max 3%
4	Pozz. Activity Index	133%	Min 105%
5	Specific Surface Area	22 m^2/gm	Min 15 m^2/gm
6	Bulk Density	601	550-700
7	+ 45 Microns	0.2%	Max 10%

4.5. Chemical admixture

4.5.1 Super plasticizer – Master Glenium sky 8233 is used.

TABLE-6 Properties of super plasticizer

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

4.6. Water

The water used for making concrete and for curing was clean and free from harmful impurities such as oil, alkali, acid etc. The properties of water are shown in table.

TABLE-7 Properties 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	Alkalinity	260 mg/litre
9	TDS	500 mg/litre

V. Mix Proportion

To produce SCC, the major work involves designing an appropriate mix proportion and evaluating the properties of the concrete thus obtained. In practice, SCC in its fresh state shows high fluidity, self-compacting ability and segregation resistance, all of which contribute to reducing the risk of honey combing of concrete. With these good properties, the SCC produced can greatly improve the reliability and durability of the reinforced concrete structures. In addition SCC shows good performance in compressive strength test and can fulfil other construction needs because its proportion has taken into consideration the requirements in the structural design.

The ingredients for SCC are similar to other plasticized concrete. It consists of cement, coarse aggregate, fine aggregate, water, and mineral and chemical admixtures.

No standard or all-encapsulating method for determining mixture proportions currently exists for SCC. However, many different proportion limits have been listed in various publications. Multiple guidelines and "rules of thumb" about mixture proportions for SCC were found.

EFNARC Specification and guidelines for self-compacting concrete 2002, since the utilization of Self-compacting Concrete (SCC) was growing rapidly. The concrete community of various European countries intensely researches its application and implements experiences. This Specification and Guideline utilizes EFNARC's broad practical experience with SCC to provide a framework for design and use of high quality SCC.

VI. Experimental Programme

The quantity of cement, fine and coarseaggregates, fly ash, silica fume, water and Superplasticizerfor each batch of proportion is preparedas mentioned in design of SCC. Then the mixing process is carried out by electric mixer machine.

6.1. TESTS FOR FRESH PROPERTIES OF SCC

6.1.1. Slump Flow test

This test involves the use of slump cone used with conventional concretes as described in ASTM C 143(2002).The main difference between the slump flow test and ASTM C 143 is that the slump flow test measures the "spread" or "flow" of the concrete sample once the cone is lifted rather than the traditional "slump" (drop in height) of the concrete sample. The T50 test is determined during the slump flow test. It is simply the amount of time the concrete takes to flow to a diameter of 50 centimeters.

6.1.2 J-Ring Test

The test is used to determine the passing ability of the concrete. The equipment consists of a open steel ring, drilled vertically with holes to accept threaded sections of reinforcement bar. These sections of bar can be of different diameters and spaced at different intervals; in accordance with normal reinforcement considerations, 3x the maximum aggregate size must be appropriate.

6.1.3. L-Box Test

To determine the hardened properties of concrete standard L-box test is an alternative to the J-ring test often used in developing SCC mixtures.

6.1.4 V-Funnel Test

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

6.1.5 U-Box Test

The U-box test can be used to determine the passing and filling ability of an SCC mix in a congested volume.

6.1.6. Specifications for fresh property test

TABLE-8 Specifications for fresh property testing

SL	Methods	Units	Min	Max
1	Slump flow	mm	650	800
2	T50 Slump flow	sec	2	5
3	J-ring	mm	0	10
4	V-funnel	sec	6	12
5	L-box (h2/h1)		0.8	1
6	U-box(h2-h1)	mm	0	30

6.2. MECHANICAL PROPERTIES TESTS

To determine the hardened properties of concrete standard tests like compression test on cubes for compressive strength, split tensile test on cylinders for tensile strength and flexural test on beams for flexural strength of concrete were carried out at 28days and 56days of curing .

6.2.1. Compression Test

Compression strength of concrete is defined as the load, which causes the failure of a standard specimen. The test of compressive strength should be made on 150mm size cubes. Place the cube in the compression-testing machine. The green button is pressed to start the electric motor. When the load is applied gradually, the piston is lifted up along with the lower plate and thus the specimen application of the load should be 300 KN per minute and can be controlled by load rate control knob. Ultimate load is noted for each specimen. The release valve is operated and the piston is allowed to go down. The values are tabulated and calculations are done.

6.2.2 Split Tensile Test

A concrete cylinder of size 150mm dia×200mm height is subjected to the action of the compressive force along two opposite edges, by applying the force in this manner .The cylinder is subjected to compression near the loaded region and the length of the cylinder is subjected to uniform tensile stress.

TABLE-9 Mix Proportions

Mix	Ceme nt Kg/m3	GGBS Kg/m3	Silica Fume Kg/m3	Fine Agg Kg/m3	Coarse Agg Kg/m3	W/C	Super Plas.0.8/% Kg/m3
Mix 1 (10% GGBS + 3% Silica fumes)	485.89	49.60	12.27	883.09	714.42	0.346	4.38
Mix 2 (10% GGBS + 6% Silica fumes)	469.14	49.60	24.54	883.09	714.42	0.348	4.35
Mix 3 (10% GGBS + 9% Silica	452.38	49.60	36.80	883.09	714.42	0.351	4.31
Mix 4 (20% GGBS + 3% Silica fumes)	430.04	99.20	12.27	883.09	714.42	0.350	4.33
Mix 5 (20% GGBS + 6% Silica fumes)	413.04	99.20	24.54	883.09	714.42	0.353	4.30
Mix 6 (20% GGBS + 9% Silica fumes)	396.53	99.20	36.80	883.09	714.42	0.356	4.26
Mix 7 (30% GGBS + 3% Silica fumes)	374.19	148.81	12.27	883.09	714.42	0.357	4.28

6.2.3. Flexural Test

Flexure test or modulus of rupture carried out on the beams of size (100mm×100mm×500mm), by considering the material to be homogeneous .The beam should be tested on a span of 400 mm for 100mm specimen by applying two equal loads placed at third points .To get these loads, a central point load is applied on a beam supported on steel rollers placed at third point. The rate of loading shall be 1.8 KN/minute for 100 mm specimens the load should be increased until the beam failed. Note the type of failure, appearance of fracture and fracture load.

6.3. DURABILITY PROPERTIES

6.3.1. Rapid Chloride Permeability Test

The data on the resistance of the high performance self-compacting concrete mixture to chloride ion penetration determined in accordance with ASTMC 1202 for the age of 28 days are shown in table.

Requirements as per ASTM C-1202-03, Table 1, Chloride ion permeability based on charge passed

VII. Results and Discussion

7.1. Fresh Properties

TABLE-10 Results of fresh properties

Mix	Flow Test Dia(mm)	J – Ring		V- funnel Test T50 (sec)	V- funnel Test T5 (sec)	L – Box Ratio	U – Box H2-H1 (mm)	pH	Temperature (^{o}C)
		Dia (mm)	H2-H1 (mm)						
Mix 1	695	605	4	8	9	0.96	11	11.10	26.56
Mix 2	682	585	6	9	10	0.93	8	11.19	26.42
Mix 3	674	567	7	7	8	0.90	4	11.37	26.83
Mix 4	693	502	3	8	9	0.92	5	11.40	27.46
Mix 5	690	595	5	8	9	0.87	5	11.78	26.75
Mix 6	686	591	5	8	8	0.85	7	11.59	27.27
Mix 7	683	588	6	8	9	0.86	7	11.26	26.92

7.2. Mechanical Properties

TABLE-11 Results of mechanical properties

Mix	Compression Strength (N/mm2)				Split Tensile Strength (N/mm2)		Flexural Strength (N/mm2)	
	7 days	28 days	56 days	90 days	28 days	56 days	28 days	56 days
Mix 1	40.44	49.91	56.06	59.23	4.44	4.92	10.50	11.35
Mix 2	42.50	51.77	64.75	67.54	4.47	4.99	11.50	12.50
Mix 3	48.22	58.68	68.90	72.73	4.85	5.05	14	14.50
Mix 4	52.72	64.82	72.92	76.85	5.27	5.24	15.25	16
Mix 5	61.50	71.89	74.97	78.83	6.10	5.72	18	17.50
Mix 6	53.93	67.97	73.67	75.36	5.55	5.16	16.50	14.25
Mix 7	50.75	64.06	69	72.67	4.86	4.96	13	12.50

7.3. Durability properties

7.3.1 Rapid chloride penetration test (RCPT)

TABLE-12 Results of RCPT

SL. No.	Charge passed	Chloride ion permeability	Mix	Total charge passed(Coulombs)
1	>4000	High	Mix 1	1824.3
2	2000-4000	Moderate	Mix 2	1613.8
3	1000-2000	Low	Mix 3	1424.6
4	100-1000	Very low	Mix 4	1247.5
5	<100	Negligible	Mix 5	1076.2
6			Mix 6	891.7
7			Mix 7	720.9

7.4. GRAPHS

7.4.1. Graphs of fresh properties

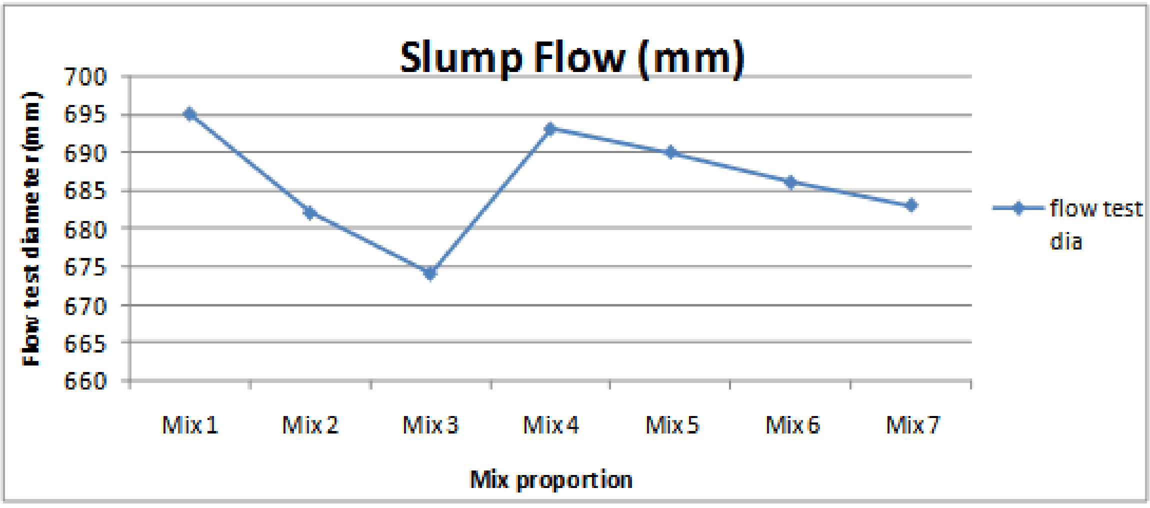

FIGURE-1 Figure shows the slump flow of various mixes

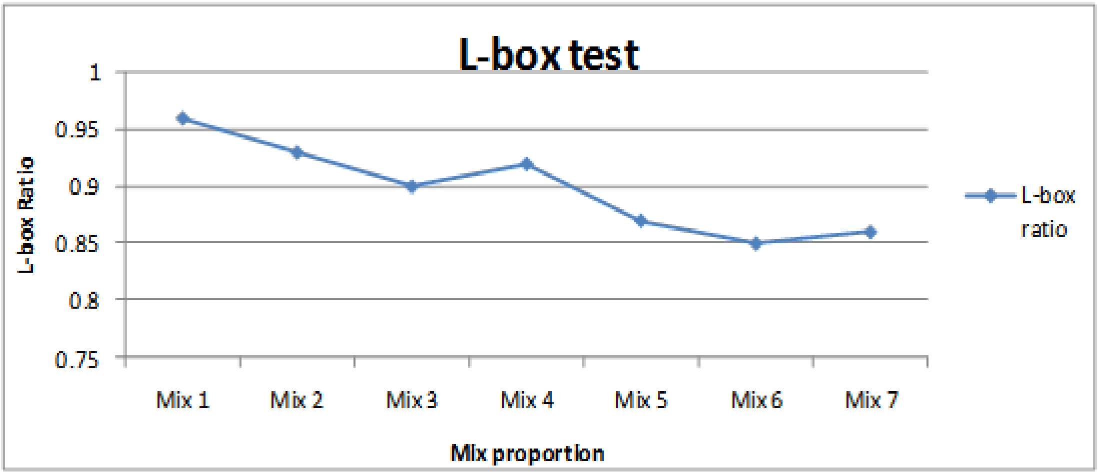

FIGURE-2 L-box results for different mix proportions

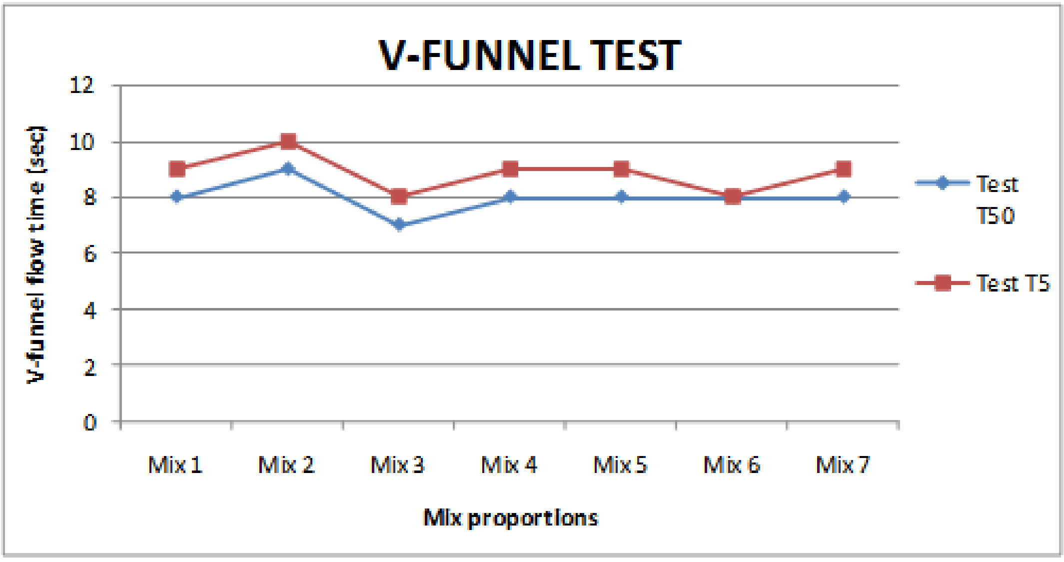

FIGURE-3 V-funnel results for different mix proportions

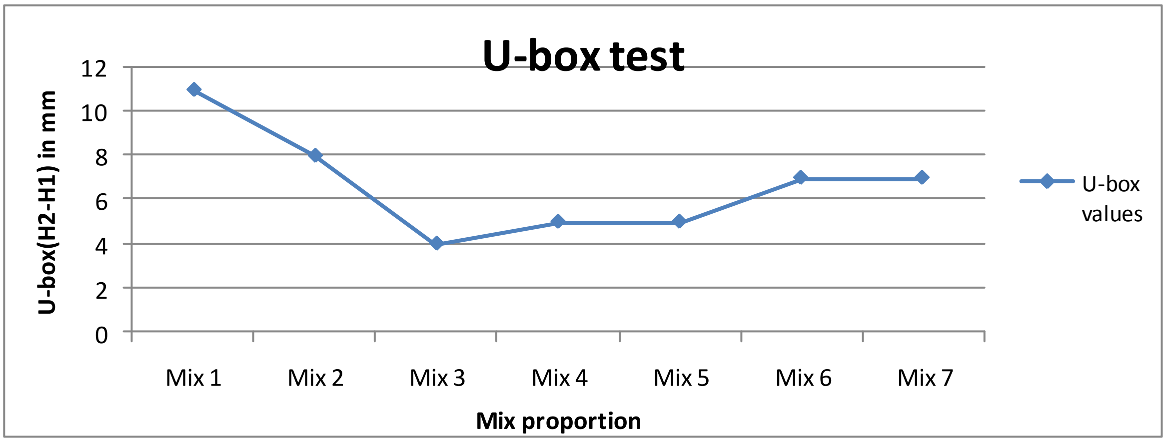

FIGURE-4 U-box results for different mix proportions

7.4.2. Graphs of mechanical properties

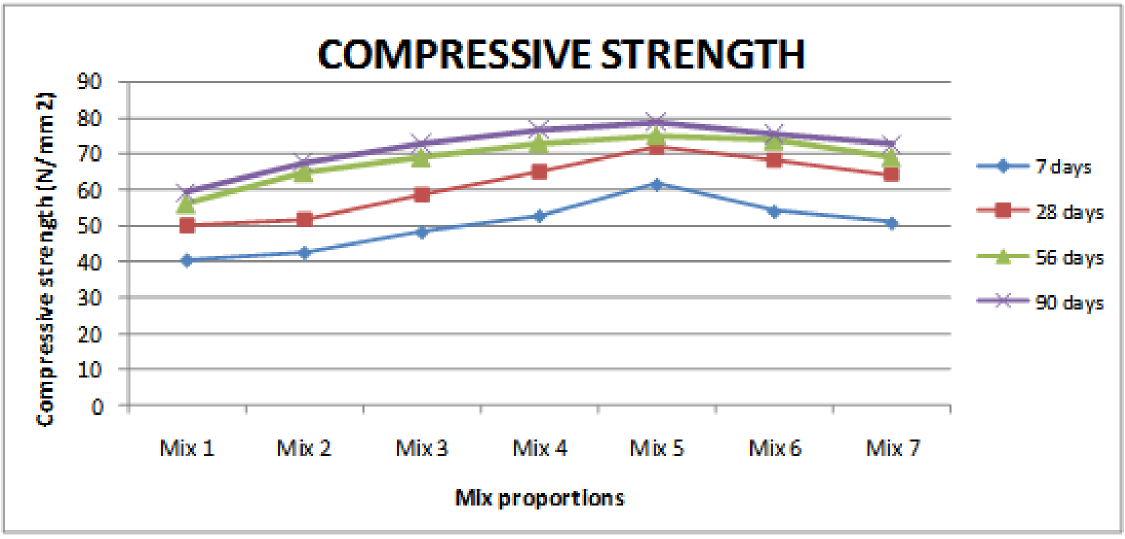

FIGURE- 5 Variation of compressive strength with different mix proportions

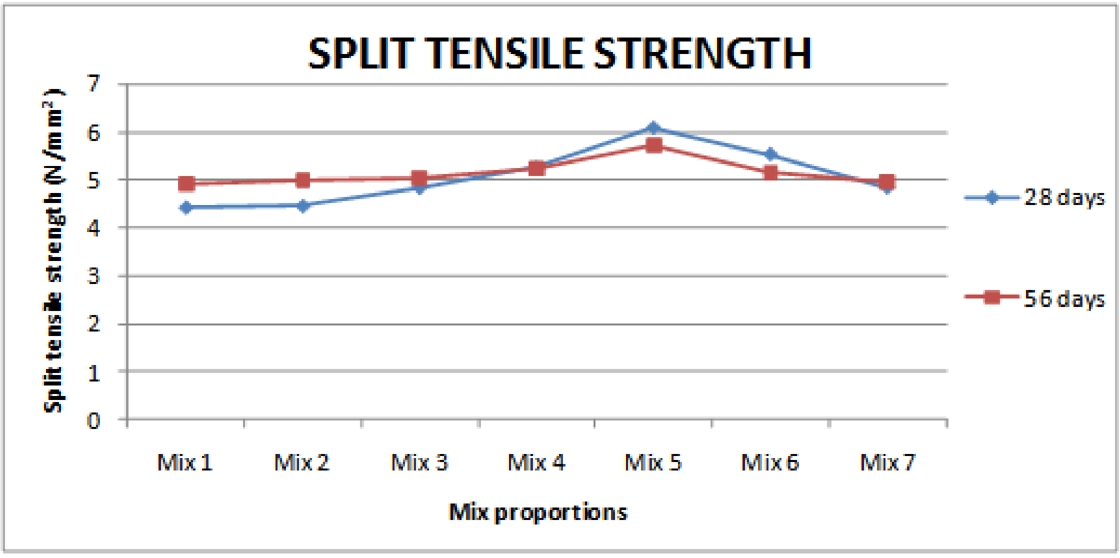

FIGURE-6 Variation of split tensile strength with different mix proportions

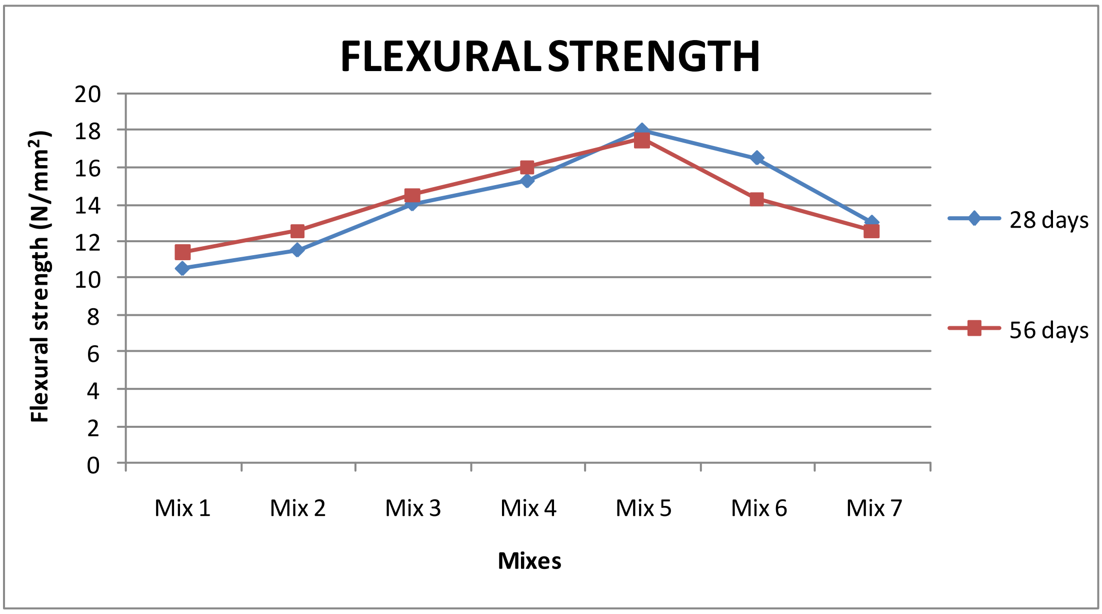

FIGURE-7 Variation of flexural strength with different mixes

VIII. Conclusion

The application of silica fume and GGBS in concrete mixture has significantly increased and enhanced the properties of the concrete whether it is in wet stage or in harden condition. Silica fume is a viable secondary mineral material. It leads to higher than usual modulus value and from the mixes studied, it is suggested that no more than 6% silica be replaced by mass. Rheological tests chosen and performed were sufficient to ascertain whether the mix will have all the attributes of SCC or not, i.e., the fresh concrete test used were sufficient to measure the filling ability and passing ability. Silica fume provide mechanical strength to high performance self compacting concrete. Addition of silica fumes develops filling and passing ability of concrete.

From the results of mechanical properties, we know that the compressive strength has shown considerable increase from 7 days curing till 56 days of curing. Similarly flexural strength has increased at that same duration but not as much as the compressive strength. In general, High performance self compacting concrete with GGBS and silica fumes exhibits better performance in compression as compared to its flexure.

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