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An Experimental Study on Ultra-High Strength Self Compacting Concrete

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Abstract: *At present the performance aspect of concrete has generated a lot of importance. This emphasis on performance has given rise to the development of Self Compacting Concrete (SCC). The features of mix proportion of SCC include low water to cementitious material ratio, high volume of powder, high paste to aggregate ratio and less amount of coarse aggregate[1]. One of the popularly employed techniques to produce Self Compacting Concrete is to use fine materials like Fly Ash, GGBFS etc; in concrete, besides cement, the idea being to increase powder content or fines in concrete. The present investigation is aimed at developing ultra high strength Self Compacting Concrete of M160 Grade. The parameter of study includes achieving desired grade of concrete by finding the ultimate compressive strength and fresh properties of concrete. SCC characteristics such as flowability, passing ability and segregation resistance have been verified using slump flow, L-box, V-funnel and U-box tests.*

Keywords: *Compressive Strength, GGBFS, Powder Content, Self-Compacting Concrete, Ultra High Strength*

I. Introduction

Building elements made of high strength concrete are usually densely reinforced. This congestion of reinforcement leads to serious problems while concreting. Using concrete that can be easily placed and spread in between the congested reinforced concrete elements can solve this problem. A highly homogeneous, well-spread and dense concrete can be ensured using such a type of concrete.

SCC was originally developed at the University of Tokyo in Japan with the help of leading concrete contractors during 1980's to be mainly used for highly congested reinforced structures in seismic regions. As durability of concrete structures was an important issue in Japan, an adequate compaction by skilled labors was required to obtain durable concrete structures. This requirement led to the development of SCC[2]. The development of SCC was first reported in 1989.Self-compaction is based on the principle that the settling velocity of a particle is inversely proportional to the viscosity of the medium in which the particle exists. It basically flows under gravity i.e. under its own weight.

Ultra High strength concrete can be produced with normal concrete. But these concretes cannot flow freely by themselves, to pack every corner of moulds and all gaps of reinforcement. Ultra High strength concrete based elements require thorough compaction and vibration in the construction process.Development of SCC is a very desirable achievement in the construction industry for overcoming the problems associated with cast-in place concrete. It is not affected by the skill of workers, shape and amount of reinforcing bar arrangement of a structure.Due to its high fluidity and resisting power to segregation, it can be pumped over longer distances. It extends the possibility of use of various by-products in its manufacturing. The use of SCC not only shortens the construction period but also ensures quality and durability of concrete. It replaces manual compaction of freshconcrete with a modern semi-automatic placing technology.

All the researchers have developed SCC taking the CA/FA ratio and also considered the limited content of coarse aggregate and more content of fines. But, there are very limited investigations reported considering the high strength in the development of SCC. Keeping this in view, the present experimental investigation is taken up to achieve ultra high strength i.e. of M160 grade of Self Compacting Concrete. Powder content is the main aspect of a SCC mix design. In the present work, only fine aggregate is used and optimum dosage of Micro Silica Fume is used in the SCC mixes as a filler material.In addition to cement GGBS was used as a fine powder material. The main objective of present investigation is to achieve high strength self-compacting concrete using PCE. As for the mix design trial and error method was used, as Indian Standard Code does not have guidelines for above 100MPa.

II. Experimental Program

Wide spread applications of SCC have been restricted due to lack of standard mix design procedure and testing methods. It is pertinent to mention that only features of SCC have been included in Indian Standard Code of practice for plain and reinforced concrete (fourth revision), [2000][3]. L-box test, V-funnel test, U-box test are recommended by EFNARC [European Federation of Producers andApplicators of Specialist Products for Structures, May 2005][4] for determining the fresh properties of self-compacting concrete.

2.1 Materials

1) Ordinary Portland Cement (53 grade)
2) River Sand
3) Water
4) GGBS
5) Silica Fume
6) Polymer Fiber
7) Steel Fiber
8) Chemical Admixture (PCE)

2.1.1 Ordinary Portland Cement

The grade of the cement used was 53 and locally available brand (Ambuja Cement) was used. The color of the cement was grey and uniform. It was checked for lumps and using hand insertion was checked for hydration.

2.1.2 River Sand

The fine aggregate used was locally available river sand without any organic impurities and conforming to IS: 383 – 1970 [Methods of physical tests for hydraulic cement][5]. The fine aggregate was tested for its physical requirements such as gradation, fineness modulus, and specific gravity and bulk density in accordance with IS: 2386 – 1963 [Methods of test for aggregate for concrete][6].

2.1.3 Water

Water used for mixing and curing was potable water, which was free from any amounts of oils, acids, alkalis, sugar, salts and organic materials or other substances that may be deleterious to concrete or steel confirming to IS: 3025 – 1964 part22, part 23[7] and IS: 456 – 2000 [Code of practice for plain and reinforced concrete]. The pH value should not be less than 6. The solids present were within the permissible limits as per clause 5.4 of IS: 456 – 2000.

2.1.4 GGBS

Locally available GGBS was used. 40% of the cement content was used in the mix design.

2.1.5 Silica Fume

Silica fume is an ultrafine material with spherical particles less than 1 μm in diameter, the average being about 0.15 μm. The specific gravity of silica fume is generally in the range of 2.2 to 2.3.

2.1.6 Polymer Fiber and Steel Fiber

Locally available brand of fibers was used. The length of the fibers was kept constant at 2 inches. Both the fibers were used 0.250 of cement and GGBS. They were of continuously deformed type and quantity used in the mix design was 2.03 kg/m^3 each.

2.1.7 Chemical Admixture

Polycarboxylic Ether (PCE) was used in the concrete mixture. (SIKA)

2.3 Mix Proportions

The proportions of concrete mixtures are summarized in **Table1. Table.2** shows corrected proportion after adding water and admixture to increase workability. Three mix designs were tested in this experiment. All three designs were prepared with target strength of 160MPa. The quantity of cement was maintained between 450 and 600 kg/m^3 for all mixtures. GGBS was used more than double the amount of cement. Quantity of PCE was 18kg/m^3. Study on mix-design by Nan Su was used as reference for this experiment [8].

Table.1

Material	Cement	Fine Aggregate	GGBS	Silica Fume	Water	PCE	Fiber
Content(kg/m^3)	580	1394	232	87	162	18	2.03
Proportion	1	2.4	0.4	0.15	0.28	0.031	0.007

Table.2

Material	Cement	Fine Aggregate	GGBS	Silica Fume	Water	PCE	Fiber
Proportion	1	2.4	0.4	0.15	0.287	0.0318	0.007

2.4 Batching And Mixing Of Scc

The proportioning of the quantity of cement, cementitious material like Flyash, fine aggregate, water and PCE has been done by weight as per the mix design. All the measuring equipments are maintained in a clean serviceable condition with their accuracy periodically checked.

The mixing process is carried out in electrically operated concrete mixer. The materials are laid in uniform layers over each other. Dry mixing is done to obtain a uniform color. The GGBS and silica fume is thoroughly blended with cement before mixing. Self-Compacting characteristics of fresh concrete are carried out immediately after mixing of concrete using EFNARC specifications [2005].

The slump was maintained in the range of 75 – 100 mm[IS: 7320 – 1974][9] and compaction factor was 0.9. In higher strength concretes, these are maintained by adjusting the mineral and chemical admixtures.

A total of 12 cubes of standard size 150 mm x 150 mm x150 mm, 12 beams of size 150mm x 150mm x 300mm and 12 cylinders of 150 mm diameter and 300 mm height were cast for determining the compressive strength and flexural strength respectively.

2.5 Fresh Properties Of Scc

2.5.1 Requirements of Self Compacting Concrete

SCC mixes must meet three key properties: [10]

1. Ability to flow into and completely fill intricate and complex forms under its own weight
2. Ability to pass through the congested reinforcement under its own weight.
3. High resistance to aggregate segregation.

Due to the high powder content, SCC shows more plastic shrinkage or creep than ordinary concrete mixes. These aspects were taken into account during designing of the SCC and for this purpose polymer and steel fibers were used. The results for fresh concrete have been tabulated in **Table.3.**

2.5.2 Results of Fresh Concrete Tests

Table.3

S No	Method	Unit	Minimum	Maximum	Result
1.	Slump Flow Test	mm	650	800	750
2.	T50 Slump Flow	sec	2	5	5
3.	V-Funnel	sec	6	12	11
4.	V-Funnel at T5	sec	6	15	13
5.	U-Box	mm	0	30	7

Fig.1 Slump Flow Test

2.6 Curing of Test Specimen

After 24 hours of casting, the specimens were removed from the moulds and immersed in clean fresh water. The specimens were cured for 7 days, 28 days, 56 days and 90 days respectively. The fresh water tanks used for the curing of the specimens were emptied and cleaned once in every fifteen days and were filled once again. All the specimens under immersion were always kept well under water.

2.7 Tests on Hardened Concrete

Testing of hardened concrete plays an important role in controlling and confirming the quality of self-compacting concrete.

2.7.1 Compressive Strength

Compressive strength of a material is defined as the value of uniaxial compressive stress reached when the material fails completely. In this investigation, the cube specimens of size 150 mm x 150 mm x 150 mm are tested in accordance with IS: 516 – 1969 [Method of test for strength of concrete][11]. The testing was done on a compression-testing machine of 300 tons capacity. The machine has the facility to control the rate of loading with a control valve. The machine has been calibrated to the required standards. The plates are cleaned; oil level was checked and kept ready in all respects for testing.

After curing, cube specimens were removed from the curing tank and dried to remove excess water. The specimens were transferred on to the swiveling head of the machine such that the load was applied centrally. The smooth surfaces of the specimen are placed on the bearing surfaces. The top plate was brought in contact with the specimen by rotating the handle. The oil pressure valve was closed and the machine was switched on. A uniform rate of loading 140 $kg/cm^2/min$ was maintained. The maximum load to failure at which the specimen breaks and the pointer starts moving back was noted. The test was repeated for the three specimens and the average value was taken as the mean strength. The test set up is shown in **Fig.2**.In the present investigation, the compressive strength test has been conducted on concrete at 7, 28, 56 and 90 days.

Fig.2 Compressive strength test setup

2.7.2 Flexural Strength

Standard beam test (Modulus of rupture) was carried out on the beams of size 150 mm x 150 mm x 700 mm as per IS: 516 [Method of test for strength of concrete], by considering that material is homogeneous. The beams were tested on a span of 600 mm for 150 mm specimen by applying two equal loads placed at third points. To get these loads, a central point load has applied on a beam supported on steel rollers placed at third point as shown in **Fig.3**. The rate of loading is 1.8 kN/minute for 150 mm specimens and the load was increased until the beam failed. Depending on the type of failure, appearance of fracture and fracture load, the flexural tensile strength of the sample was estimated.

As explained earlier, in the present investigation, the flexural strength test has been conducted on concrete at 7, 28, 56 and 90 days.

If 'a' is the distance between the line of fracture and the nearer support, then for finding the modulus of rupture, these cases should be considered [12].

1) When a > 133 mm for 150 mm specimen

$f_{cr} = PL/bd^2$, where P = total load applied on the beam

2) When 110 mm < a < 133 mm, $fcr = 3Pa/bd^2$
3)When a < 110 mm, the result should be discarded.

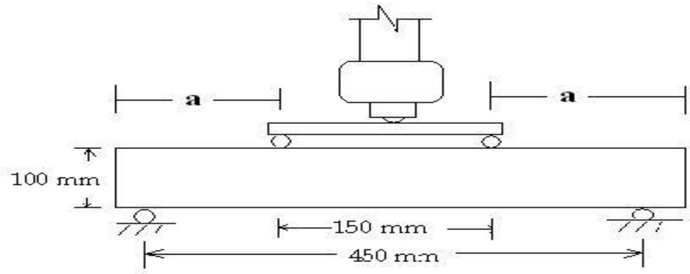

Fig.3 Schematic diagram for flexure test setup

2.7.3 Results on Hardened Concrete

Table.4

Testing Days	Characteristic Compressive Strength in MPa	Flexural Strength in MPa
7	74.4	6.4
28	110	9.8
56	137.5	13.9
90	158	16.1

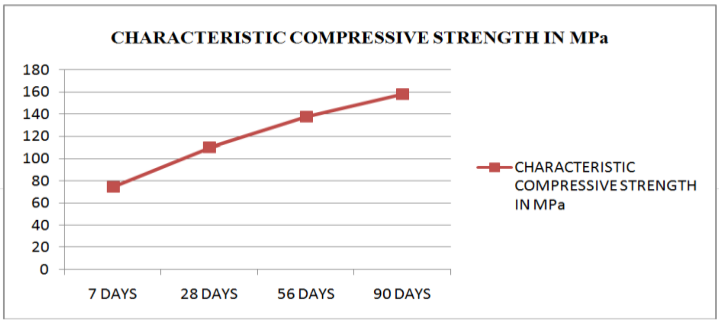

Fig.4

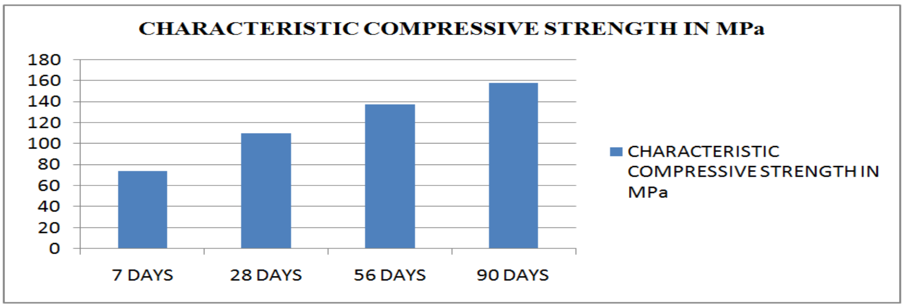

Fig.5

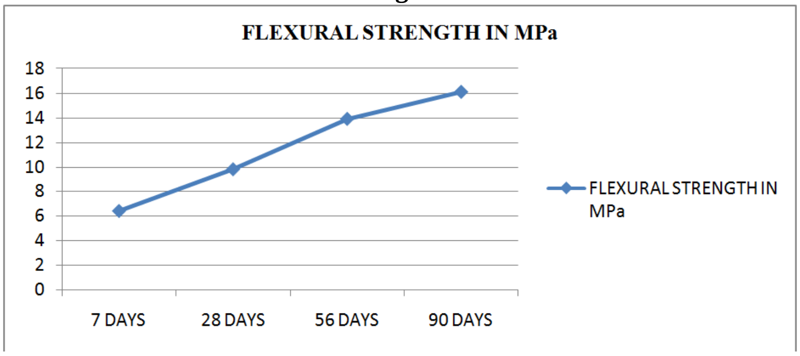

Fig.6

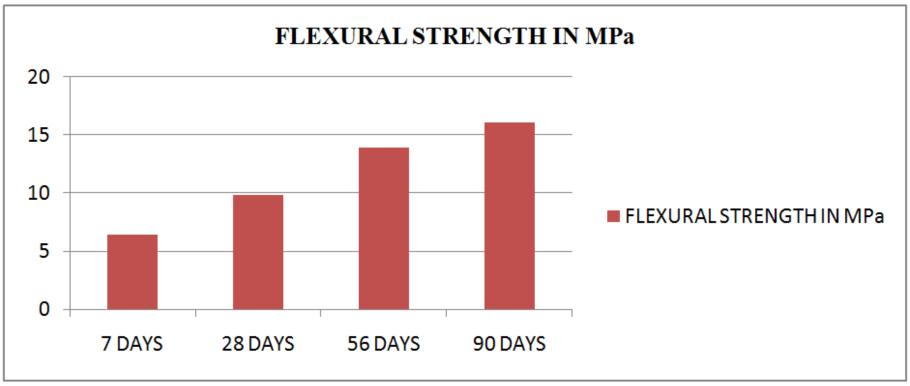

Fig.7

III. Conclusion

The Indian Standard Code does not have mix-design criteria for SCC above 100MPa, which has created a huge obstacle. With this study we have attempted to create an ultra high strength SCC, which can be used in places, which require high strength concrete but have high congestion,which make it difficult to achieve compaction. The next task would be to use this study as reference and create SCC of even higher grade using variations in the mix design and maybe set a guideline in the IS Code for SCC of higher grades of concrete. We would have truly achieved something of significance when ultra high strength self-compacting concrete is used as standard concrete instead of "special concrete" and is seen for what it really is i.e. reliable and durable.

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