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Self Compacting High Performance Concrete with Steel Fibres

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Abstract: ***This paper presents the experimental procedure for the design of self-compacting concrete, in which we proposed the mix design with the globally acceptance result of all tests and the carried out test are slump flow test, V-funnel test, L-box test. The mix design consists of 25% fly ash (as a cement replacement material), 1.2% superplastizer and steel fibres. The compressive strength, split tensile strength and flexural strength was checked on the 7-day, 14-day, 28-day and results are indicating that the proposed design mix can produce self-compacting concrete with higher quality. High-performance concretes are made with carefully selected high-quality ingredients and optimized mixture designs; these are batched, mixed, placed, compacted and cured to the highest industry standards. Typically, such concretes will have a low water-cementing materials ratio of 0.20 to 0.45. Plasticizers are usually used to make these concretes fluid and workable. High-performance concrete almost always has a higher strength than normal concrete. However, strength is not always the primary required property. This paper also describes the test performed for the globally acceptance for the characteristics for self-compacting concrete such as slump flow, V-funnel, L-box test. Strength of concrete is determined for the 7-day, 14-day, 28-day are also mentioned. To establish an appropriate mixture proportion for a self-compacting concrete the performance requirements must be defined taking into account the structural conditions such as shape, dimensions, reinforcement density and construction conditions. The construction conditions include methods of transporting, placing, finishing and curing. The specific requirement of self-compacting concrete is its capacity for self-compaction, without Conventional concrete tends to present a problem with regard to adequate consolidation in thin sections or areas of congested reinforcement, which leads to a large volume of entrapped air voids and compromises the strength and durability of the concrete. Self-compacting concrete (SCC) can eliminate the problem, since it was designed to consolidate under its own mass.***

Keywords: self compacting high performance concrete, EFNARC, Super-plasticizer (SP), Viscosity Modifying Agent (VMA)

1. Introduction

Self compacting concrete (SCC) is the new category of high performance concrete characterized by its ability to spread and self consolidate in the formwork exhibiting any significant separation of constituents. The elimination of vibration for compacting concrete during placing through the use of Self Compacting Concrete leads to substantial advantages related to better homogeneity, enhancement of working environment and improvement in the productivity by increasing the speed of construction. Self-compacting concrete was designed by a simple mix design proposed by Nan Su. SCC was developed in 1988's by Prof. Hagime Okamura in Japan. SCC was one of the special concrete in across the world. Self Compacting Concrete consist of the same components as conventionally vibrated concrete, i.e. cement, aggregates, steel fibres and water, with the addition of chemical and mineral admixtures in different proportions. Usually, the chemical admixtures used are Superplasticiser and viscosity-modifying agents, which change the rheological properties of concrete. Mineral admixtures are used as an extra fine material, and in some cases, they replace cement.

High-performance concrete (HPC) exceeds the properties and constructability of normal concrete. Normal and special materials are used to make these specially designed concretes that must meet a combination of performance requirements. Special mixing, placing, and curing practices may be needed to produce and handle high-performance concrete. Extensive performance tests are usually required to demonstrate compliance with specific project needs (ASCE 1993, Russell 1999, and Bickley and Mitchell 2001). High-performance concrete has been primarily used in tunnels, bridges, and tall buildings for its strength, durability, and high modulus of elasticity. It has also been used in shotcrete repair, poles, parking garages, and agricultural applications.

Self-compacting concrete is a new innovative construction material which shows the property of flow ability under its own weight without segregation and bleeding, this type of concrete doesn't need any type of compaction when placed. It is generally used to place in the area where the congested reinforcement is placed and the places where compaction to the concrete is not possible. The successful design of self-compacting concrete must be homogeneous, durable, dense and having the same engineering properties likewise the traditional concrete. High-Performance-Concrete (HPC) is a concrete made with appropriate materials combined according to a selected mix design; properly mixed, transported placed, consolidated and cured so that the resulting concrete will give excellent performance in the structure in which it is placed, in the environment to which it is exposed and with the loads to which it will be subject for its design life.

To meet the concrete performance requirements the following three types of self-compacting concretes are available.

a) **Powder type of self-compacting concrete**: This is proportioned to give the required self- compatibility by reducing the water-powder (material<0.1mm) ratio and provide adequate segregation resistance. Super plasticizer and air entraining admixtures give the required deformability.

b) **Viscosity agent type self-compacting concrete**: This type is proportioned to provide self-compaction by the use of viscosity modifying admixture to provide segregation resistance. Super plasticizers and air entraining admixtures are used for obtaining the desired deformability.

c) **Combination type self-compacting concrete**: This type is proportioned so as to obtain self-compactability mainly by reducing the water powder ratio, as in the powder type, and a viscosity modifying admixture is added to reduce the quality fluctuations of the fresh concrete due to the variation of the surface moisture content of the aggregates and their gradations during the production. This facilitates the production control of the concrete.

2. Literature Review

2.1 Studies on High-Performance Concrete

Mix proportions for high-performance concrete (HPC) are influenced by many factors, including specified performance properties, locally available materials, local experience, personal preferences, and cost. With today's technology, there are many products available for use in concrete to enhance its properties. The primary application for HPC have been structures requiring long service lives such as oil drilling platform, long span bridges and parking structures. HPC still requires good construction practice and good curing to deliver high performance. High-Performance-Concrete (HPC) has been defined as concrete that possesses high workability, high strength and high durability. ACI (American Concrete Institute) has defined HPC as a concrete in which certain characteristics are developed for a particular application and environment. Under the ACI definition durability is optional and this has led to a number of HPC structures, which should theoretically have had very long services lives, exhibiting durability associated distress early in their lives. ACI also defines a high-strength concrete as concrete that has a specified compressive strength for design of 6, 000 psi (41 MPa) or greater.

A mix of high performance concrete was described by **Ozawa et al. (1990**), which is defined as a concrete with high filling capacity. It can be filled into all the corners of formwork without using any vibrators. The objective of this study was to investigate the role of chemical admixtures such as superplasticizer, steel fibres and viscosity agents on the deformational and segregation behavior of fresh concrete. The study is important for developing the concrete with high filling capacity. The optimum mix proportion of superplasticizer and viscosity agent was clarified for the concrete with high filling capacity. It was found that there exists the suitable viscosity of paste for improving not only the deformability but also the segregation resistance, which is highly dependent on the volume of free water in fresh concrete.

Mehta and Aitcin (1990) suggested the term High-Performance-Concrete (HPC) for concrete mixtures that possess the following three properties: high workability, high-strength, and high durability. Durability rather than high strength appears to be the principal characteristic for high-performance concrete mixtures being developed for use in hostile environments such as seafloor tunnels, offshore and coastal marine structures, and confinement for solid and liquid wastes containing hazardous materials.

HPC was defined by **Forster (1994)** as "a concrete made with appropriate materials combined according to a selected mix design and properly mixed, transported, placed, consolidated, and cured so that the resulting concrete will give excellent performance in the structure in which it will be exposed, and with the loads to which it will be subjected for its design life.".

Nima Farzadni et al. (2011) say that with a fast population growth and a higher demand for housing and infrastructure, accompanied by recent developments in civil engineering, such as high-rise buildings and long-span bridges, higher compressive strength concrete is needed. Currently, high-performance concrete is used in massive volumes due to its technical and economic advantages. Such materials are characterized by improved mechanical and durability properties resulting from the use of chemical and mineral admixtures as well as specialized production processes.

2.2 Studies on Superplasticizers

Superplasticizers are widely used in concrete processing to increase the rheological properties of hardened pastes. Super plasticizers are chemical admixtures which can maintain an adequate workability of fresh concrete at low water/cement ratio for a reasonable period of time, without affecting the setting and hardening behaviour of the cementitious system. Superplasticizers are introduced in concrete like many other admixtures to perform a particular function; consequently they are frequently described according to their functional properties. Super plasticizers have been classified as high range water reducers (HRWR) to distinguish them from other categories of less effective water reducers.

Franklin (1976) stated that, super plasticizers are organic polyelectrolytes, which belong to the category of polymeric dispersants. The performance of super plasticizers in cementitious system is known to depend on cement fineness, cement composition mode of introduction to the mixture etc., as well as on the chemical composition of super plasticizers. For many years, it was not possible to reduce water/cement ratio of concrete below 0.40 till the advent of super plasticizers. The super plasticizers were first used in concrete in 1960s and their introduction occurred simultaneously in Germany and Japan (Meyer and Hottori, 1981). At first, the super plasticizers were used as fluidizers than water reducing agents. By using large enough super plasticizer, it was found possible to lower the water/binder ratio of concrete down to 0.30 and still get an initial slump of 200mm. Reducing the water/binder ratio below 0.30 was a taboo until Bache reported that using a very high dosage of super plasticizers and silica fume, water binder ratio can be reduced to 0.16 to reach a compressive strength of 280MPa (Bache, 1981).

Aitcin et al. (1991) reported, that by choosing carefully, the combination of Portland cement and superplasticizer, it was possible to make a 0.17 water/binder ratio concrete with 230mm slump after an hour of mixing which gave a compressive strength of 73.1MPa at 24 hours but failed to increase more than 125MPa after long term wet curing. During 1980s, by increasing the dosage of super plasticizers little by little over the range specified by the manufacturers, it is realized that super plasticizers can be used as high range water reducers (**Ronneberg and Sandvik, 1990).**

Super plasticizers can be used for three different purposes or combination reducing agents. By using large enough super plasticizer, it was found possible to lower the water/binder ratio of concrete down to 0.30 and still get an initial slump of 200mm. Reducing the water/binder ratio below 0.30 was a taboo until Bache reported that using a very high dosage of super plasticizers and silica fume, water binder ratio can be reduced to 0.16 to reach a compressive strength of 280MPa **(Bache, 1981).**

Super plasticizers can be used for three different purposes or a combination concrete and no segregation was observed. For mixtures with water cement ratios between 0.3 and 0.45, the slump diameters were between 500 mm and 740 mm and the compressive strength varied between 53 MPa and 68 MPa at 28 days of age. In their work, Roncero (1999) et al. evaluated the influence of two super plasticizers (a conventional melamine based product and a new-generation comb-type polymer) on the shrinkage of concrete exposed to wet and dry conditions. Tests of cylinders with embedded extensometers have been used to measure deformations over a period of more than 250 days after casting. In general, it was observed that the incorporation of super plasticizers increased the drying shrinkage of concretes when compared to conventional concretes, whereas it did not have any significant influence on the swelling and autogenous shrinkage under wet conditions. The melamine-based product led to slightly higher shrinkage than the comb-type polymer. It must be realized that the introduction of super plasticizer in concrete involves a new chemical component in a complex hydraulic binder system, which already contain several added chemicals.

3. Properties of SCC

3.1 Fresh SCC Properties:

The three main properties of SCC in plastic state are;

a) Filling ability (excellent deformability)
b) Passing ability (ability to pass reinforcement without blocking)
c) High resistance to segregation

3.2 Hardened Properties of SCC:

Self compacting concrete and traditional vibrated concrete of similar compressive strength have comparable properties and if there are differences, these are usually covered by the safe assumptions on which the design codes are based. However, SCC composition does differ from that of traditional concrete as they are mixed in different proportions and the addition of special admixtures to meet the project specifications for SCC. Durability, the capability of a concrete structure to withstand environmental aggressive situations during its design working life without impairing the required performance, is usually taken into account by environmental classes. This leads to limiting values of concrete composition and minimum concrete covers to reinforcement.

4. Composition of SCC

Materials used in this investigation:

- **Cement**: Commercially available Ordinary Portland cement (OPC) 53 grade manufactured by Birla shakti Company was used. Literally, cement means a binding material. It has the property of setting and hardening when mixed with water to attain strength. The cement may be natural or artificial. Natural cement is manufactured by burning and then crushing natural cement stones, which contain argillaceous and calcareous matter. Artificial cement is manufactured by burning appropriately proportioned mixture of argillaceous and calcareous materials at a very high temperature and then grinding the resulting burnt mixture to a fine powder.

- **Coarse aggregate**: The coarse aggregate from a local crushing unit having 12mm normal size well-graded aggregate according to IS was used in this investigation. The coarse aggregate procured from quarry was sieved through 20mm, 16mm, 12.5mm, 10mm and 4.75mm sieves. The material passing through 12.5mm IS sieve was used in this investigation.

- **Fine Aggregate**: The fine aggregate was obtained from a nearby river course. The sand obtained was sieved through all the sieves (i.e.4.75mm, 2.36mm, 1.18mm, 600µ, 300µ, 150µ). Sand passing through 4.75mm IS sieve was used.

- **Flyash**: Waste materials from Thermal Power Plant. Fly ash is an industrial waste product dumped by fired power plants. Continued experiments and researches in the area of industrial waste management have resulted in successful utilization of fly ash in to a powerful medium in the construction industry.

- **Super-Plasticizer:** The super plasticizer used in this experiment is Glenium 51. It is manufactured by BASF construction chemical India pvt ltd, Mumbai.

- **Viscosity Modifying Agent (V.M.A)**: Glenium Stream 2 which is manufactured by BASF construction chemical India pvt.ltd, Mumbai and it is a premier ready-to-use, liquid, organic, viscosity modifying admixture (VMA) specially developed for producing concrete with enhanced viscosity and controlled rheological properties. Concrete containing GLENIUM STREAM 2 admixture exhibits superior stability and controlled bleeding characteristics, thus increasing resistance to segregation and facilitating placement.

Figure 1: VMA (GLENIUM STREAM 2)

- **Water**

This is the least expensive but most important ingredient of concrete. Water, which is used for making concrete, should be clean and free from harmful impurities such as oil, alkali, acid, etc. In general, water which is fit for drinking should be used for making concrete.

- **Steel fibre**

Steel fibre mixed into the concrete can provide an alternative to the provision of conventional steel bars or welded fabric in some applications. The concept has been in existence for many years and it has been used in limited range of applications: among the first major uses was the patching of bomb craters in runways during the World War II. However, it was during the 1970s that commercial use of this material began to gather momentum, particularly in Europe, japan and the USA.

5. Preliminary Investigation

5.1 Properties of cement

Manufacturer	Birla shakti cement
Specific gravity	3.08
Fineness	5%
Standard consistency	26.75%
Initial setting time	115

5.2 Properties of fine aggregates

Specific gravity of Fine aggregate 2.47.
Fineness modulus of fine aggregates2.41

Table 1: Sieve analysis of fine aggregate

Sieve size (mm)	Mass retained (g)	Cumulative mass retained (g)	Cumulative % mass retained	Cumulative % finer
4.75	0	0	0	100
2.36	12	12	1.2	98.8
1.18	124	136	13.6	86.4
0.60	323	459	45.9	54.1
0.30	357	816	81.6	18.4
0.15	173	989	98.89	1.1
Fineness modulus:2.41				

5.3 Properties of Coarse aggregates

Specific gravity of Coarse aggregate = 2.71

Fineness modulus of coarse aggregates: 6.62

Table 2: Sieve analysis of coarse aggregates

Sieve size(mm)	Mass retained (g)	Cumulative mass retained (g)	% mass retained	Cumulative % mass retained
40	0	0	0	0
20	39	39	1.3	1.3
10	1779	1818	59.3	60.6
4.75	1183	3001	39.4	100
2.36	0	3001	0	100
1.18	0	3001	0	100
0.60	0	3001	0	100
0.30	0	3001	0	100
0.15	0	3001	0	100
Fineness modulus:6.62				

6. Mix Design

1) Characteristic strength of concrete at 28 days in field= 40 N/mm^2.

Maximum size of aggregate = 12mm.
Compaction Factor (CF) = 0.8.
Specific gravity of Fine aggregate = 2.47.
Specific gravity of Coarse aggregate = 2.71.
Specific gravity of Cement = 3.08.
Target mean strength (fck) = fck+ 1.65*s
For M40 grade standard deviation, s=6.6(from table 1 of IS-10262)
fck = 40+1.65*6.6 =**50.89 N/mm^2**.

2) Selection of w/c ratio

- From fig 1 of IS-10262-1982 for 50.89 N/mm2, it is 0.31.
- From durability aspect maximum water content for moderate exposure is 0.6 (from IS-456-2000)

The lesser of the above two is to be adopted. Hence 0.31 is taken.

From table 5 of IS-10262-1982 the water content per cubic meter of concrete is

Water content = 196 Kg/m^3. (Interpretation)

Assume: FA/TA=28.
W/c=0.31.
Workability=0.8CF

Table 3.conditions with correction factors

Change in condition	corrections	
	water	%FA/TA
w/c	0	0
CF	0	0
Zone I	0	0
Total correction	0	0

Cement=196/0.31=632 Kg/m3. As per durability minimum cement content for moderate exposure is 272Kg/m3.(from IS-456-2000).

As per SCC mix specifications the cement is limited to 500Kg/m3 for medium grade concrete.
P=28%

Entrapped air = 2.8% of volume of concrete as per table 3 of IS-10262-1982.

Determination of FA content:

V=(W+(C/Sc)+(1/P)*(FA/SFA)*(1/1000)
FA=425 Kg
FA/TA=.28
TA=1520Kg
CA=1095Kg

W: C: FA: CA
196: 500: 425: 1095
0.392: 1: 0.85: 2.19 Converting into SCC proportions:

The normal mix proportions are modified as per EFNARC specifications and different trial mixes were tested. By considering the fresh properties, we finally arrived at the following SCC proportions

Table 4: mix proportions

Trial no.	W/C	Cement + Flyash (Kg)	Fine agg (Kg)	Coarse agg (Kg)	Water (lt)	Glenium 51+ Stream 2 (lt)
1	0.392	500	425	1095	196	5
2	0.38	500	650	870	190	2.5
3	0.4	500	650	870	200	5
4	0.45	500	650	870	225	5
5	0.5	500	650	870	250	5
6	0.45	500	760	760	225	10

7. Fresh Properties of SCC

There are many test methods to measure the fresh properties of **SCC** but we only use the following methods**:**

Slump flow
V- funnel
L- Box

Table 5: Slump flow values

Trial no.	T 500mm (sec)	600-800(mm)
1	5.5	600
2	15	510
3	7.56	585
4	6	575
5	4.2	690
6	2.6	720

Table 6: V-FUNNEL Values

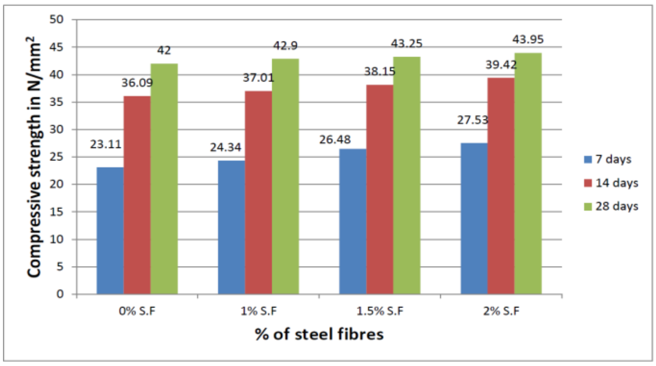
Trial mix	V-Funnel (6 -12)sec	T 5min
1	Blockage	Blockage
2	Blockage	Blockage
3	31	Blockage
4	28	33.5
5	9.5	24.3
6	8.7	10.2

Table 7: L-BOX Values

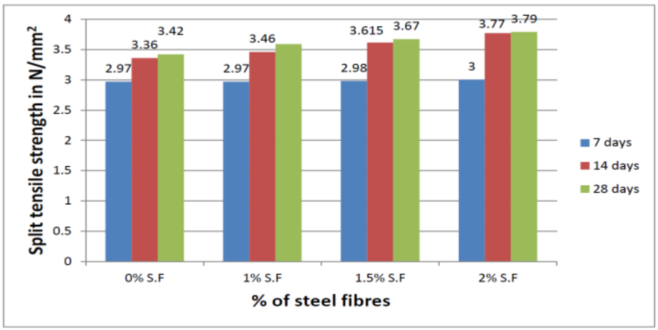
Trial mix	L Box (0.8-1)
1	Blockage
2	Blockage
3	0.75
4	0.72
5	0.812
6	0.904

8. Testing of Hardened Concrete

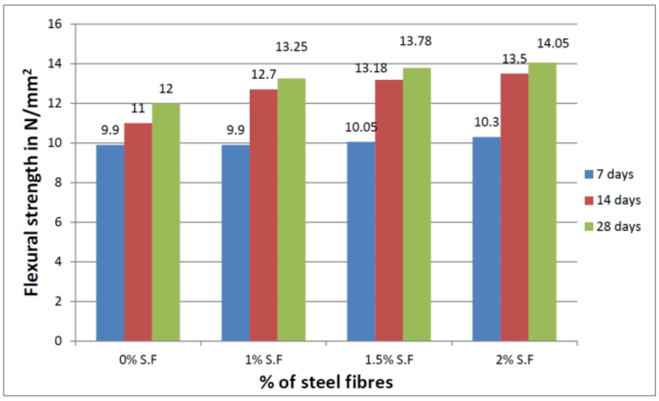
8.1.1 Compressive strength



8.1.2 Split Tensile Strength



8.1.3 Flexural Strength



9. Conclusion

The above experimental program leads to emphasize the effects of steel fibre on properties of fresh and hardened steel fiber reinforced high performance concrete. It is observed from the results that the presence of steelfiber increases the overall performance of the high performance concrete. The enhancement in engineering properties has clearly shown in all the above mentioned experiments. Basically the superiority of the self-compacting concrete mainly lies in the strength and durability characteristics of the high performance concrete mixture.

The main objective of the present investigation was to study the behavior of steel fiber reinforced self compacting high performance concrete (SFRHPSCC) loading. Preliminary investigation was also conducted to arrive at an optimum dosage rate of steel fibers. The fresh and hardened properties of SFRHPSCC specimens were also studied and compared the results with that of ordinary high performance self compacting concrete. The conclusions of the present investigation and the scope for the future work are presented in this paper. Addition of steel fibers has increased ultimate load than that of conventional HPSCC beams under flexure.

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