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R. Ravi
Student Visvodaya Engineering College, Kavali, SPSR Nellore, Andhra Pradesh, India.

Sumanth Doodala
Assistant Professor, Department of Civil Engineering, Sri Sidhartha Engineering College, Hyderabad, Telangana, India.

Correspondence
R. Ravi
Student Visvodaya Engineering College, Kavali, SPSR Nellore, Andhra Pradesh, India.

An experimental study on strength & flowability of self-compacting concrete

R. Ravi, Sumanth Doodala

Abstract

Self-compacting concrete (SCC) is a development of conventional concrete, in which the use of vibrator for compaction is no more required. Self-compacting concrete was first developed in 1988 to achieve durable concrete structures. Since then, various investigations have been carried out and this type of concrete has been used in practical structures in Japan, mainly by large construction companies. Investigations for establishing a rational mix-design method and self-compactability testing methods have been carried out from the viewpoint of making self- compacting concrete a standard concrete.

In the present work two grades M20 SCC mix was developed using EAFNARC mix design concept to arrive at the proportions of aggregate. Compressive strength tests were conducted to know the strength properties of the mixes. A simple mix design procedure has been developed using EAFNARC mix design on SCC. Compressible packing model is used to arrive at the proportion of aggregates, cement content and fly ash content are obtained from previous studies and modified accordingly as per EAFNARC standards to achieve optimum mix proportions satisfying fresh properties, hardened properties and also economy.

Keywords: self-compacting concrete, flyash, super plasticizer.

Introduction

Self-compacting concrete (SCC) represents one of the most significant advances in concrete technology for decades. Inadequate homogeneity of the cast concrete due to poor compaction or segregation may drastically lower the performance of mature concrete in-situ. SCC has been developed to ensure adequate compaction and facilitate placement of concrete in structures with congested reinforcement and in restricted areas.

SCC was developed first in Japan in the late 1980s to be mainly used for highly congested reinforced structures in seismic regions (Bouzoubaa and Lachemi, 2001) [1]. As the durability of concrete structures became 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 and its development was first reported in 1989 (Okamura and Ouchi, 1999) [2].

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 reinforcement bars (Zhu *et al.,* 2001) [3]. SCC can also be used in situations where it is difficult or impossible to use mechanical compaction for fresh concrete, such as underwater concreting, cast in-situ pile foundations, machine bases and columns or walls with congested reinforcement. The high flowability of SCC makes it possible to fill the form work without vibration (Khayat *et al.,* 2004) [4].

Since its inception, it has been widely used in large construction in Japan. Recently, this concrete has gained wide use in many countries for different applications and structural configurations.

It can also be regarded as "the most revolutionary development in concrete construction for several decades". Originally developed to offset a growing shortage of skilled labor, it is now taken up with enthusiasm across all countries for both site and precast concrete work. It has proved beneficial economically because of a number of factors as noted below (Krieg, 2003 and Enfarc, 2005):

i. Faster construction,

ii. Reduction in site manpower,
iii. Easier placing,
iv. Uniform and complete consolidation,
v. Better surface finishes,
vi. Improved durability,
vii. Increased bond strength,
viii. Greater freedom in design,
ix. Reduced noise levels, due to absence of vibration, and
x. Safe working environment.

Objective of the research

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 honeycombing of concrete. With these good properties, the SCC produced can greatly improve the reliability and durability of the reinforced concrete structures. Self-compactability can be largely affected by the characteristics of materials and the mix- proportion. In literature we can find that most of the researchers produce self- compacting concretes by high volume replacement or addition of fly ash, Bagasse ash etc. to Ordinary Portland Cement. In the present work SCC mix (M20) was developed. A simple mix design procedure based on COMPRESSIBLE PACKING MODEL and EAFNARC mix design model was used with some modifications to arrive at the aggregate proportions. To qualify the Self-Compacting Concrete mixes Slump flow, V-funnel, L-flow tests were conducted and the fresh properties obtained are checked against the specifications given in EFNARC Specifications. Compressive strength tests were conducted to know the strength properties of the mixes. Initially a simple mix design was followed and modifications were made accordingly while arriving at trial mixes to get an optimized mix which satisfies both fresh, hardened properties and economy. Finally a simple mix design for OPC based SCC was arrived on the lines of Nansu mix design. hence the main objective of the research is to arrive at the CA/FA proportions in a systematic approach using the CPM method as against the nansu method where CA/FA was assumed against based on trials thus the CPM method fixes the amount of CA and FA very important in the design of SCC mixes.

Materials used

The different materials used in this work are

1 53 Grade ordinary portland Cement
2 Fine Aggregate(zone II)
3 Coarse Aggregate
4 Mineral admixtures (Fly ash, Metakaolin and Silica fume)
5 Super Plasticizer (structuro100)
6 Water

Cement: Cement used in the investigation was 53 Grade ordinary Portland Cement confirming to IS: 12269. The cement was obtained from a single consignment and of the same grade and same source. Procuring the cement it was stored properly. The Specific gravity of the cement is found to be 3.15

Fine Aggregate: The fine aggregate conforming to Zone-II according to IS: 383 were used. The fine aggregate used was obtained from a nearby river source.

Table 1: Properties of fine aggregates

Bulk density	1.64 g/cc
Specific gravity	2.4

Coarse Aggregate: Crushed granite Aggregate was used as coarse aggregate. The coarse aggregate was obtained from a local crushing unit having 20mm MSA, 20mm 16mm, and 10mm well graded aggregate according to IS: 383 is used in this investigation.

Table 2: Properties of coarse aggregates

Bulk density	1.5 g/cc
Specific gravity	2.65

Fly ash: Fly ash confirming to is3812:1981 is used as mineral admixture. Mineral admixtures are used to improve the fresh and hardened properties of concrete and at the same time reduce the cost of concrete materials. In order to achieve the necessary viscosity to avoid segregation, additional fine materials are used.

Silica fume: Silica fume also referred to as micro silica or condensed silica fume, is another material that is used as an artificial pozzolanic admixture. It is a product resulting from reduction of high purity quartz with coal in an electric and furnace in the manufacture of silicon or ferrosilicon alloy. Silica fume rises as oxidized vapors. It cools, condenses and is collected in cloth bags. It is further processed to remove impurities and to control particle size. It is extremely fine with particle size less than I micron and with an average diameter of about 0.1 micron, about 100 times smaller than average cement particles. Silica fume has specific surface area of about 20,000m /kg, as against 230 to 300 m /kg that of cement. Metakaolin Considerable research has been done on activated ordinary clay and kaolinitic clay. These un purified materials have often been called as “Metakaolin”. High reactive metakaolin is made by water processing to remove unreactive impurities to make 100% reactive pozzolan. Such a product white or cream in color, purified, thermally activated is called a “high reactive metakaolin”. High reactive metakaolin shows high pozzolanic reactivity and in $Ca(OH)_2$ even as early as one day. The high reactive metakaolin is having the potential to complete with silica fume. Metakaolin that we have used in this project work was contributed by “ASTRRA CHEMICAS IN CHENNAI” CALCINED CLAY – HIMACEM is a High Reactivity Metakaolin (HRM), which is manufactured by the high temperature treatment of specially selected kaolin under controlled conditions. It is a white mineral admixture, having very good pozzolanic properties. It reacts with free lime produced during the hydration of cement to form additional cementitious products.

Super plasticizer: High range water reducing admixtures known as super plasticizers are used for improving the flow or workability for decreased water-cement ratio without decreasing the compressive strength. These admixtures when they disperse in cement agglomerates significantly decrease a viscosity of the paste by forming a thin film around the cement particles. In the present work water- reducing admixture Structuro 100(M) is differentiated from conventional super plasticizers in that it is based on a unique carboxylic ether polymer with long lateral chains. This greatly improves cement dispersion. At the start of the mixing process an electrostatic dispersion occurs but the cement particle’s capacity to separate and disperse. This mechanism considerably reduces the water demand in flowable concrete. Structuro 100(M) combines the properties of water reduction and workability retention. It allows the production of high performance concrete and/or concrete with high workability. Structuro 100(M) is a particularly strong superplasticizer allowing production of consistent concrete properties around the required dosage.

Water:

Potable water was used in the experimental work for both mixing and curing.

Mix Design Procedure

To produce SCC, the major work involves designing an appropriate mix proportion and evaluating the properties of the concrete thus obtained. As a part of mix design aggregate proportions are calculated using compressible packing model. Cement quantity and fly ash content are obtained from previous literature and these are modified according to EFNARC specifications to get fresh, hardened properties and economical mixes.

Step 1: Calculation of Coarse aggregate and Fine aggregate

The packing factor (PF) of aggregate is defined as the ratio of mass of aggregate of tightly packed state in SCC to that of loosely packed state. Clearly, PF affects the content of aggregates in SCC. A higher PF value would imply a greater amount of coarse and fine aggregates used, thus, decreasing the content of binders in SCC. Consequently, its flowability, self-compacting ability and compressive strength will be reduced. On the other hand, a low PF value would mean increased dry shrinkage of concrete. As a result, more binders are required, thus, raising the cost of materials. In addition, excess binders used would also affect the workability and durability of SCC. Therefore, it is important to select the optimal PF value in the mix design method so as to meet the requirements for SCC properties, and at the same time taking economic feasibility into consideration. The content of fine and coarse aggregates can be calculated as follows.

Wg=PF x Wgl x (1-(s/a)) Ws=PF x Wsl x (s/a)

Where Wg= Content of coarse aggregates in SCC (kg/m3);

Ws= Content of fine aggregates in SCC (kg/m3);

Wgl=Unit volume mass of loosely piled saturated surface-dry coarse aggregate in air (kg/m3);

Wsl=Unit volume mass of loosely piled saturated surface-dry fine aggregates in air (kg/m3);

PF = Packing factor;

(s/a) = volume ratio of fine aggregates to total aggregates

Obtaining aggregate proportion using CPM

In practice, the measurement of φ (REAL PACKING DENSITY), is done by pouring a dry sample of mass Ms in a cylinder of cross section S and height h. The corresponding packing index is K = 4.1. The calculation of φ is as follows:

- total volume V of the packing:

V = S.h

- real volume v of the aggregate:

v = Ms/BRD

(BRD = Bulk Relative Density)

Φ = v/V = Ms / (S.h.BRD)

The virtual packing density of a single component mixture is denoted βi

βm = (1+1/K)φ

K = compaction index which depends on method of compaction

= 4.1 for pouring

= 4.5 for sticking with rod

= 4.75 for vibration

= 9 vibration and compaction 10kPa

Container wall effect

The above measured packing density βmis a confined packing density, since it is altered by the wall effect, called q, induced by the walls of the cylinder.

In the case of a mono-sized aggregate of size d, the virtual density βm, must be corrected to obtain the non-confined virtual packing density, according to the relation:

βi = qβm

q = 1/ (1−(1− kw)(1-(1−di/dc)2(1-di/h)))

kw is a coefficient linked with the form of the grains, equal to 0.88 for rounded grains and 0.73 for crushed grains.

di = diameter of the aggregate

dc = diameter of the cylindrical container

h = height of the container

The overall virtual packing density ϒi for a mixture of any number of particle size classes with independent beta values is defined by the following equation where the value yi represents the volume fraction of the ith size class when each of the i size classes to be mixed are measured in beakers before combination.

$$\Upsilon i = \beta i/[1 - \sum 11 - \beta i + bij\, 11 - \frac{1}{\beta j} yj$$

$$- \sum 11 - \frac{aij\beta i}{\beta j} yi \;]$$

The proportion corresponding to least virtual packing density is taken for determining the packing factor.

Loosening Effect

The loosening effect describes an effect whereby the introduction of small particles forces apart larger particles. The theoretical basis for this was a curve fit of an analysis of several researchers data over the course of more than 50 years.

aij =(1 − (1 −dj/di)1.02)0.5

The value di represents is the average particle diameter.

di = (dmax.dmin)0.5

dmax = diameter of the largest particle in the group.

dmin = diameter of the smallest particle in the group.

Wall effect due to particles

The wall effect describes an effect whereby larger particles cause interstitials in the mixture which are too small to be filled by other particle classes. The theoretical basis for this was a curve fit of an analysis of several researchers data over the course of more than 50 years.

bij = 1 − (1 −di/dj)1.50

In the table shown in the appendix the dark rows show the proportions with the least virtual packing density. We chose these proportions for calculating the packing factor and there by coarse aggregate and fine aggregate. Corresponding packing factors and the mix proportions are shown in the following table.

Calculations are shown in the appendix.
Step 2: Calculation of POWDER Content
To secure good flowability and segregation resistance, the content of binders (powder) should not be too low. However, too much cement used will increase the drying shrinkage of SCC.
EFNARC has given guidelines for calculating powder content. And from the previous studies
We fixed the cement content and fly ash content is decided by minimum powder content according to EFNARC specification. (The total powder content to be maintained in SCC is 450-600 kg/m3 as per EFFNARC Specifications.)
Step 3: Determining the mixing water content
Although factors such as content of fine and coarse aggregates, material proportions, and curing age can affect the compressive strength of SCC, the ratio of water to binders by weight (W/B) is the most prominent determinant of compressive strength The smaller the PF value, the more the paste volume in SCC will be. As a result, the compressive strength becomes higher. Water content is obtained through trial mixes.

Step 4: Determining SP dosage.
Adding an adequate dosage of SP can improve the flowability, self-compacting ability and segregation resistance of fresh SCC for meeting the design requirements.
Optimum dosage of structuro100 should be determined with trial mixes. As a guide, a dosage range of 500 ml to 1500ml per 100kg of cementitious material is normally recommended.

Step 5: Trial batches and tests on SCC
Trial mixes can be carried out using the contents of materials calculated as above. Then, quality control tests for SCC should be performed to ensure that fresh and strength properties described in the chapter are satisfied.
In the event that satisfactory performance cannot be obtained, then adjustments should be made until all properties of SCC are satisfied. For example, when the fresh SCC shows poor flowability, the PF value is reduced to increase the binder volume and to improve the workability. Depending on the apparent problem, the following courses of action might be appropriate:

1) Using additional filler.
2) Modifying the proportions of the sand or the coarse aggregate.
3) Using a viscosity modifying agent, if not already included in the mix.
4) Adjusting the dosage of the super plasticizer and/or the viscosity modifying agent.
5) Adjusting the dosage of admixture to modify the water content, and hence the water/powder ratio.

Sample calculation of the proposed method is given in APPENDIX.

Experimental Program

The experimental program can be identified in two stages, first, to develop SCC mixes for M20 grade which satisfy specifications given by EFNARC to qualify SCC and developing a simple mix design for producing SCC with OPC.
The program consisted of arriving at mix proportions, weighing the ingredients of concrete accordingly, mixing them in a standard concrete mixer of rotating drum type of half bag capacity and then testing for the fresh properties of SCC. If fresh properties satisfy EFNARC specifications, Standard cylinders of dimensions 150mmx300mm were caste to check whether the target compressive strength is achieved at 7-days and 28- days curing. If either the fresh properties or the strength properties are not satisfied, the mix is modified accordingly. Standard cylinder moulds of 150mmx300mm made of cast iron were used for casting. The standards moulds were fitted such that there are no gaps between the plates of the moulds. If there small gaps they were fitted with plaster of paris. The moulds then oiled and kept ready for casting. After 24 hours of casting, the specimen were demoulded and transferred to curing tank where in they were immersed in water for the desired period of curing.

Results and Discussions

1. Fresh Properties of Concrete:

A. Slump-Flow Test:

Flow ability test is one of the most commonly used SCC tests at the current time. This test involves the use of slump cone used with conventional concretes as described in ASTM C 143(2002). The main difference between the Flow ability test and ASTM C 143 is that the Flow ability 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. Typically, slump flow values of approximately 24 to 30 inches are within the acceptable range; acceptable T50 times range from 2 to 5sec.

Table 3: Flow values for different admixture of SCC

S.No	Type of Concrete	flow value(mm)		
		Direction-1	Direction-2	Average
1.	SCC with flyash	620	650	635
2.	SCC with metakaolin	640	660	650
3.	SCC with silicafume	660	680	670

B. L-BOX TEST:

The L-box value is the ratio of levels of concrete at each end of the box after the test is complete at each end of the box. The L- box consists of a “chimney “section and a “trough “section after the test is complete, the level of concrete in the chimney is recorded as H1,the level of concrete in the trough is recorded as H2. The L-box value (also referred to as the “L-box ratio”, “blocking value”, or “blocking ratio”) is simply H2/H1. Typical acceptable values for the L-box value are in the range of 0.8 to 1.0. If the concrete was perfectly level after the test is complete, the L-box value would be equal to 1.0. Conversely, if the concrete was too stiff to flow to the end of the trough the L-box value would be equal to zero.

Table 4: L-Box test values for different admixture of SCC

S.No	Type of Concrete	H2/H1 value		
		H1(cm)	H2(cm)	H2/H1
1.	SCC with flyash	12	9	0.75
2.	SCC with metakaolin	14	10	0.71
3.	SCC with silicafume	15	13.5	0.90

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

Table 5: V-funnel test values for different admixture of SCC

S.No	Type of Concrete	Time taken (sec)
1.	SCC with flyash	12
2.	SCC with metakaolin	10
3.	SCC with silicafume	8

2. Harden Properties of Concrete:

A. Compressive Strength Test

Compression test is the most common test conducted on hardened concrete, partly because it is easy test to perform, and partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.

The cube specimen of size 15cm X 15cm X 15cm was cast to test various concrete mixtures for compressive strength. The cubes after de moulding were stored in curing tanks and on removal of cubes from water at 7 days and 28 days the compressive strength was conducted. The water and grit on the cubes was removed before testing the cubes. The test was carried as per IS: 516- 1959.

Fig 1: Compressive strength of concrete

Table 6: Compressive strength values for different admixture of SCC

S.No	Type of Concrete	Compressive strength (N/mm2)	
		7 days	28 days
1.	SCC with flyash	13.80	24.70
2.	SCC with metakaolin	11.11	27.22
3.	SCC with silicafume	12.7	29.88

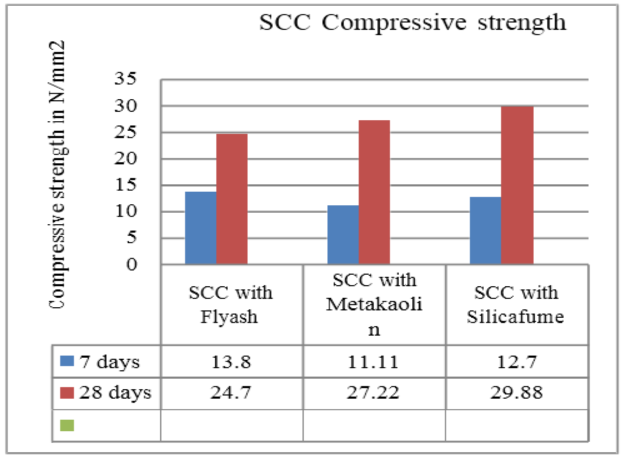

Fig 2: Compressive strength values for different admixture of SCC

B. TNSILE STRENGTH TEST

A concrete cylinder of size 150mm dia×300mm height is subjected to the action of the compressive force along two opposite edges, by applying the force in this manner.
Horizontal tensile stress=2P/πDL
Where P=the compressive load on the cylinder.
L=length of the cylinder D=dia of cylinder

Fig 3: Tensile strength of concrete

Table 7: Tensile strength values for different admixture of SCC

S.No	Type of Concrete	Tensile strength (N/mm2)	
		7 days	7 days
1.	SCC with flyash	1.627	1.627
2.	SCC with metakaolin	1.471	1.471
3.	SCC with silicafume	1.598	1.598

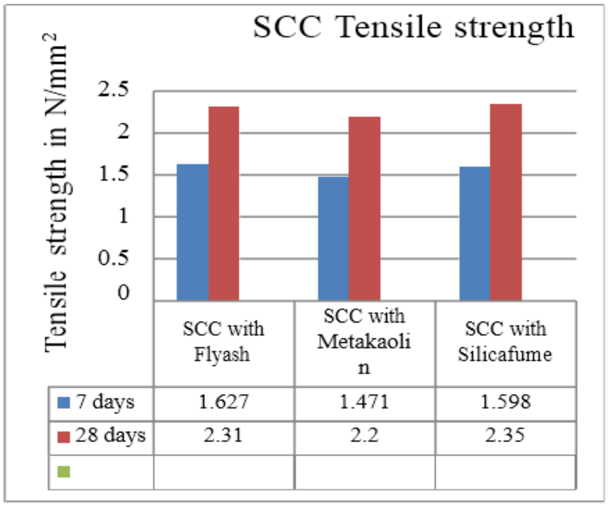

Fig 4: Tensile strength values for different admixture of SCC

Conclusions

Based on the investigation conducted for the study of behavior of self-compacting concrete the following conclusions are arrived.

1. As no specific mix design procedures for SCC are available mix design can be done with conventional EFNARC method and suitable adjustments can be done as per the guidelines provided by different agencies. 2. Trail mixes have to be made for maintaining flow ability, self compactibility and obstruction clearance. 3. From the fresh properties of SCC, we can observe that adding silica fume as an admixture can improve the flow ability, self compactibility ,obstruction clearance and filling ability of SCC than fly ash and metakaolin. From compressive and tensile strength test results for 28 days curing, we can conclude that SCC with silicafume almost reached the target strengths of M20 grade concrete for 28 days curing. And SCC with flyaash & Metakaolin has not reached the target strength of M20 grade concrete for 28 days curing. 4. Therefore from the above conclusions, we can say that the SCC for maintaining flow ability, self-compatibility and obstruction clearance may be obtained by adding silicafume as an admixture rather than flyash and metakaolin.

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