Comparison of Strength of High Strength SCC using Rounded Coarse Aggregate and Angular Coarse Aggregates

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***Abstract* - A self compacting concrete (SCC) is a type of concrete that gets compacted under its self weight. It is commonly defined as the concrete, which can be placed and compacted into every corner of formwork, purely means of its self weight by eliminating the need of either external energy input from vibrators or any type of compacting effort.**

SCC is technologically advanced due to its characteristics such as flow ability, passing ability and segregation resistance combined with altered rheology. This study aims to focus on the possibility of using rounded coarse aggregate instead of angular coarse aggregate. Tests are carried out to obtain the fresh and hardened properties of SCC and to compare the same for High strength SCC using rounded coarse aggregate and angular coarse aggregate. The attempt has been made to obtain compressive strength & Flexural strength for M70 grade of SCC using NAN-SU Method.

Keywords- Self compacting concrete, Silica Fume, Rounded, angular, coarse aggregate.

1. INTRODUCTION

Self-compacting concrete (SCC) is an advanced type of highly flowable, non-segregating concrete that is able to flow under its own mass without vibration and through congested reinforcement. With the rapid development of construction of mega structures the world over, and having the problems of congestion of reinforcement in principal structural members the demand for Self Compacting Concrete (SCC) application is increasing.

SCC can be produced using the same ingredients as that of normal concrete. The proportioning of SCC mix is much more scientific than that of conventional concrete mixes. SCC mix requires high powder content, lesser quantity of coarse aggregate, superplasticizer or Viscosity Modifying Agent (VMA) to give stability and fluidity to concrete mix. The workability of SCC is equilibrium of fluidity, deformability, filling ability and resistance to segregation. This equilibrium has to be maintained for a sufficient time period to allow for its transportation, placing and finishing. Combinations of tests are required to characterize the workability properties.

Self-compacting concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, no concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength, earlier demoulding and faster use of elements and Strength, earlier demoulding and faster use of elements and structure Concrete is being placed, reducing the exposure of workers to noise and vibration.

Any concrete is susceptible to the change in shape and size of coarse and fine aggregate. The rounded shape coarse aggregate has lesser surface area than angular one. It requires less cement to produce required bond at the same time it provides less bonding area. It offers less resistance to flow hence can improve the rheology .These aspects shall be studied in detail hence comparison of strength properties of high strength SCC using normal angular coarse aggregate and using rounded shape coarse aggregate has been studied in this project.

The development of Self Compacting Concrete can be assumed to be the most important one into the building material's domain. This is due to the benefits that this concrete offers:

- ✓ The SCC mixes have good deformability enabling them to maintain homogeneity at fresh state. It can be placed & compacted under its self weight with little or no vibration effort & which is at the same time is cohesive enough to be handled without segregation & bleeding.
- ✓ SCC offers a rapid rate of concrete placement with faster construction times & ease of flow around congested reinforcement.
- ✓ SCC can be used for all types of structures due to the fact that it can be pumped at long distances without any of its segregation.
- ✓ The use of SCC reduces the exposure of the workers to sound intensities that are as low as one tenth of those produced when placing traditional vibrated concrete
- ✓ From the contractors point of view, costly labour operations are avoided, improving the efficiency of the building site.
- ✓ Faster placement with less labour.

- ✓ Very good finishing surfaces of the elements made with Self Compacting Concrete, which is a cut in remedial costs.

Construction practice and performance, combined with the health and safety benefits, makes SCC a very attractive solution for both precast concrete and civil engineering construction.

SCC is mainly used in highly congested reinforced concrete structure in seismic region and to overcome the problem of storage of skilled labours for the efficient compaction of concrete. Review of literature indicates that durability of SCC largely depends on the type of mineral admixtures.

1.1 Requirements for Self Compacting Concrete

SCC can be designed to fulfill the requirements regarding density, strength development, final strength and durability.

Due to the high content of powder, SCC may show more plastic shrinkage or creep than ordinary concrete mixes. These aspects should therefore be considered during designing and specifying SCC. Current knowledge of these aspects is limited and this is an area requiring further research. Special care should also be taken to begin curing of concrete as early as possible.

The workability of SCC is higher than the highest class of consistence and can be characterized by the following properties.

- ✓ Filling ability
- ✓ Passing ability
- ✓ flowing ability
- ✓ Segregation resistance

A concrete mix can only be classified as Self-compacting concrete if the requirements for all three characteristics are fulfilled. SCC differ conventional concrete in that its fresh properties are vital in determining whether or not it can be placed satisfactorily. The various aspects of workability which control its Filling ability, passing ability and Segregation resistance all need to be carefully controlled to ensure that its ability to be placed remains acceptable.

1.2 Properties of Fresh SCC

A concrete mix is called Self Compacting Concrete if it fulfills the requirement of filling ability, passing ability and resistance to segregation.

- Filling ability: - The property of SCC to fill all corner of a formwork under its own weight is known as filling ability. Filling ability reflects the deformability of SCC, i.e. the ability of fresh concrete to change its shape under its own weight (Okamura and Ozawa, 1995). Deformability includes two aspects: the deformation capacity is the maximum ability to deform, that is, how far concrete can flow; and deformation velocity refers to the time taken for the concrete to finish flowing, that is, how fast concrete can flow. Filling ability is a balance between deformation capacity and deformation velocity. For example, a concrete with high deformation capacity and very low deformation velocity tends to be very viscous and would take long time to fill the formwork.
- Passing ability:-The property of SCC to flow through reinforcing bars without segregation or blocking. .Passing ability is unique to SCC. It determines how well the mix can flow through confined and constricted spaces and narrow openings, which ensures its particular applications in densely reinforced structures such as bridge decks, abutments, tunnel linings or tubing segments. It depends on the risk of blocking which results from the interaction between constituent materials and obstacles
- Resistance to segregation: - The property of SCC to flow without segregation of the aggregates. Segregation resistance is sometimes called 'stability'. Since SCC is composed of materials of different sizes and specific gravities, it is susceptible to segregation. Segregation includes that between water and solid or between paste and aggregate or between mortar and coarse aggregate in both stationary and flowing states.

2. LITERATURE REVIEW

A. NavaneethakrishnanV.M.Shanthi.

NAN SU et.al. (2001) [3] carried out an investigation on a Simple mix design for Self Compacting concrete. Compared to the method developed by the Japanese Ready-Mixed Concrete Association (JRMCA), this method is simpler, easier for implementation and less time-consuming, requires a smaller amount of binders and saves cost. Zoran Grdicet. al., (2008) [4]studied the properties of self compacting concrete with different types of additives and this work presents the properties of self compacting concrete, mixed with different types of additives:, silica fume,. Selvamonyet.al. [5] in his Investigations on Self - Compacted Self - Curing Concrete using Lime stone powder and Clinkers indicated the use of silica fume in Concrete significantly increased the dosage of super plasticizer (SP). Silica fume can better reducing effect on total water absorption while quarry dust and lime powder will not have the same effect, at 28 days. Kazumasa Ozawa [6] carried out a research on the Development of Self compacting concrete.

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Self-compacting concrete has to fulfill contradictory requirements of high flowing ability when it is being cast and high viscosity when it is at rest, in order to prevent segregation and bleeding. These requirements make the use of mineral and chemical admixtures essential for self-compacting concrete. High flowing ability is achieved using super plasticizers, while stability against segregation is achieved either by using a large quantity of fine materials, or by using appropriate viscosity modifying agents. The results of an experimental research carried out to investigate the effect of dosages of superplasticizer on compressive strength of self- compacting concrete.

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The selection of mixture proportions for self-consolidating concrete (SCC) is controlled, to a large extent, by aggregate characteristics. The changes in mixture proportions necessary to achieve the requisite workability characteristics for SCC can have significant consequences for economy and hardened properties. An ongoing research project at the International Center for Aggregates Research (ICAR) is evaluating the relationship between aggregate characteristics and SCC flow properties, with the objectives of identifying optimal aggregate characteristics for SCC and determining methods of proportioning SCC mixtures for any given set of aggregate characteristic workability.

3. PROJECT OBJECTIVES

The objective of the present project is therefore to identify the possibility of use of rounded coarse aggregate in high strength SCC with satisfactory fresh and hardened properties. The objectives of the project are:

- Selection of mix design methods, tests, properties and constituent materials.
- To compare the fresh properties like flow ability, passing ability and segregation resistance of SCC using rounded coarse aggregate and angular coarse aggregate.
- To compare the compressive and flexural strength of SCC using rounded coarse aggregate and angular coarse aggregate.

3.1 Properties of Constituent Materials

3.1.1 Cement

Selection of the type of cement will depend on the overall requirements for the concrete, such as strength, durability, etc. Ordinary Portland cement shall be normally used for producing SCC.

3.1.2. Aggregates

Fine Aggregate

All normal concreting sands are suitable for SCC both crushed or rounded sands can be used. Siliceous or calcareous sands can be used.

The amount of fines less than 4.75 mm is to be considered as fine aggregate and is very important for the rheology of the SCC. The river sand having specific gravity 2.6 was used. The results of aggregate sieve analysis are expressed by a number called Fineness Modulus. Obtained by adding the sum of the cumulative percentages by mass of a sample aggregate retained on each of a specified series of sieves and dividing

the sum by 100. The specified sieves are: 150 µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm, and 4.75 mm.

Table No.1: Results of Sieve Analysis of Fine Aggregate

$$\text{Fineness modulus} = \frac{278.35}{100} = 2.78$$

Sieve size	Percentage of Individual Fraction retained by mass	Percentage Passing, by mass	Cumulative Percentage retained by Mass
4.75 mm	00	100	00
2.36 mm	5.85	94.15	5.85
1.18 mm	18.2	75.95	24.05
600 µ	38.1	37.85	62.15
300 µ	26.8	11.05	88.95
150 µ	8.40	2.65	97.35
pan	2.65	00	-
Total	100		278.35

Angular Coarse Aggregate

All types of angular aggregates are suitable. The nominal maximum size is generally 10-12 mm. The crushed aggregate passing through 16mm sieve and retained on 10mm sieve was used. It has specific gravity 2.9.The shape of aggregate is an important characteristic since it affects the workability of concrete. It is difficult to describe the shape of irregular shaped aggregates. Not only the type of parent rock but also the type of crusher used also affects the shape of the aggregate produce. Poor grading may give a harsh mix at low workabilities and segregation at high workabilities. Effect on admixtures is small. Elongated or flaky aggregates may cause workability difficulties.

Rounded Coarse Aggregate

Rounded coarse aggregate obtained from river sand are used, having specific gravity 2.86.Rounded aggregates would provide a better flowability and less blocking potential for a given water-to-powder ratio, compared to angular and semi-rounded aggregates.

3.1.3 Admixture

The most important admixtures are the Super plasticizers (high range water reducers). The superplasticizer used was Glenium B223 from BASF. It is a Polycarboxylic ether based superplasticizer. A pozzolanic powder Silica fume was used. It was obtained from ELKEM India Pvt. Ltd. Its specific gravity was 2.2.

4. MIX DESIGN

4.1 NAN-SU method for mixture Proportion procedure for SCC.

For M70 grade of concrete

- Weight density of sand $= \dfrac{\text{weight of sand}}{\text{volumn of cube}}$

$$= \frac{1.636}{0.1 \times 0.1 \times 0.1}$$

$$= 1636\ \text{Kg/m}^3$$

- Weight density of coarse aggregate $= \dfrac{\text{weight of sand}}{\text{volumn of cube}}$

$$= \frac{1.586}{0.1 \times 0.1 \times 0.1}$$

$$= 1586\ \text{Kg/ m}^3$$

The steps to be followed under the mixture proportion procedure are briefly explained below.

Step 1: Calculation of quantity of Fine and Coarse aggregate.

$$W_{fa} = PF\ W_{fal} \times \frac{s}{a}$$

$$W_{ca} = PF \times W_{cal} \times \left(1 - \frac{s}{a}\right)$$

Where,

s/a – Ratio of fine aggregate to total mass aggregate.

W_{fa}– Mass of the fine aggregate per cum.

W_{ca}– Mass of the coarse aggregate per cum.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 09, September-2016

W_{fal}– Unit volume mass of fine aggregate
W_{cal}– Unit volume mass of coarse aggregate

$$W_{fa} = PF \times W_{fal} \times \frac{s}{a}$$

$$W_{fa} = 1.16 \times 1636 \times 0.55$$

$$= 1005.81 \text{ Kg/m}^3$$

$$W_{ca} = PF \times W_{cal} \times (1 - \frac{s}{a})$$

$$W_{ca} = 1.16 \times 1586 \times (1\text{-}0.55)$$
$$= 864.68 \text{ Kg/m}^3$$

Step 2: Calculation of cement content

$$C = \frac{fc}{20}$$

Where,
f_c - designed strength of the concrete

$$f_c = 70 \times 145.45$$
$$= 10181.5 \text{ Psi}$$

$$C = \frac{10181.5}{20} = 524 \text{ Kg/m}^3$$

As per IS-456 the cement content is much more therefore we restricted it to 400 kg/m^3.

Step 3: Calculation of mixing water content required by cement.

$$W_{wc} = \frac{W}{C} \times C$$

Where,
W_{wc} - Mixing water content required by cement, kg/m^3
W/C – The water-cement ratio by weight, which can determine by compressive strength.

$$W_{wc} = 0.32 \times 400$$
$$= 128 \text{ Kg/m}^3$$

Step4: Calculation of quantity of filler

$$V_{pf} = 1 - \frac{W\,ca}{1000 \times G\,ca} - \frac{Wfa}{1000 \times Gfa} - \frac{C}{1000 \times G\,c} - \frac{Ww}{1000 \times G\,w} - Va$$

Amount of filler required $W_f = \frac{(V\,pf \times 1000 \times Gf)}{(1 + \left(\frac{W}{p}\right) \times Gf}$

Where,
Wf– mass of filler,
Va– Air content in %
W/p – water powder ratio
Gf – Sp. gravity of filler

$$V_{pf} = 1 - \frac{864.68}{2.88 \times 1000} - \frac{1005.81}{2.6 \times 1000} - \frac{400}{3.15 \times 1000} - \frac{128}{1000} - 0.015$$

$$= 0.043$$

$$W_f = \frac{(0.043 \times 1000 \times 2.38)}{(1 + 0.32 \times 2.38)} = 54.04 \text{ Kg/m}^3$$

Step 5: water required for filler.

$$W_{wf} = \frac{W}{F} \times W_f$$

$$= 0.32 \times 54.04$$

$$= 17.29 \text{ Kg/m3}$$

Step 6: Calculation of mixing water content needed in SCC.

$$W_w = W_{wc} + W_{wf}$$
$$= 128 + 18.59$$
$$= 145.29 \text{ Kg/m}^3$$

Table No.2: Mix Proportion

Cement	Fine aggregate	Coarse aggregate	Filler
524	1005.81	864.68	54.04

This mix did not fulfill the criteria for fresh properties of SCC as well as IS provisions. Few modifications were made in the above reference mix and trials were conducted. Following mix satisfied the fresh properties of SCC. Hence other tests were carried out on this mix only.

Table No.3: Final Mix Proportions

Cement	Fine aggregate	Coarse aggregate	Silica fume	Water	Super plasticizer
409	856	735	201	197	12.87

Mix proportion in Kg per m^3 of concrete.

All the specimens were demoulded on next day of casting & immersed in curing tank for required days of curing (3,7,28 &90 days)

5. TEST ON SELF COMPACTING CONCRETE (SCC)

5.1 Tests on Fresh SCC

The main characteristics of SCC are the properties in the fresh state. SCC mix design is focused on the ability to flow under its own weight without vibration, the ability to flow through heavily congested reinforcement under its own Weight and the ability to obtain homogeneity without segregation of aggregates.

Several test methods are available to evaluate these main characteristics of SCC. The tests have not been standardized by national or international organizations. The more common tests used for evaluating the compacting characteristics of fresh SCC are described below.

1. The Slump Flow Test
2. The L- Box Test
3. The V-Funnel Test

Table-4 gives the recommended values for different tests given by different researchers for mix to be characterized as SCC.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 09, September-2016

Table No.4: Recommended Limits for Different Properties by EFNARC

Sr. No.	Property	Range
1.	Slump Flow Test	600-800 mm
2.	V-funnel	6-12 sec.
3.	L-Box H_2/H_1	≥ 0.8

5.1.1 Slump Flow Test

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete.

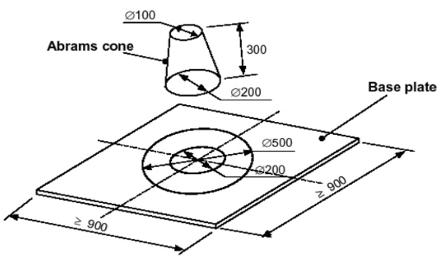


Fig. 1: Base plate and Abrams cone

5.1.2 L - Box Test Method

It assesses filling and passing ability of SCC. The vertical Section is filled with concrete, and then gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the heights 'H_1' and 'H_2' are measured. Closer to unity value of ratio 'H_2/H_1' indicates better flow of concrete.

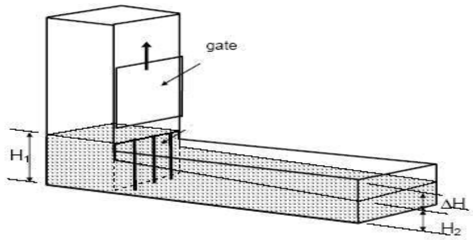


Fig. 2: L-Box Apparatus

5.1.3 V- Funnel Test

The test measures flow ability and segregation resistance of concrete. The test assembly is set firmly on the ground and the inside surfaces are moisture. The trap door is closed and a bucket is placed underneath. Then the apparatus is completely filled with concrete without compaction. After filling the concrete, the trap door is opened and the time for the discharge is recorded.

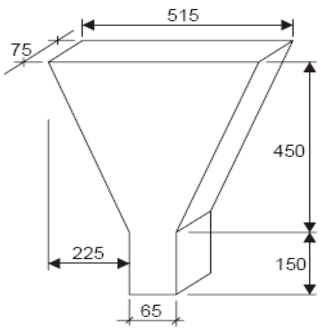


Fig.3: V-funnel apparatus

5.2 Compressive Strength

SCC with a similar water cement or cement binder ratio will usually have a slightly higher strength compared with traditional vibrated concrete, and this is due to an improved interface between the aggregate and hardened paste due to absence of vibrations.

Cube specimen of size 100mm x 100mm x 100mm were used.12 no. of specimen were cast for each type of SCC. The compressive strength at 3,7,28 &90 days was determined in Compression Testing Machine.

5.3Flexural strength

For the SCC of specified strength, class and maturity, the tensile strength may be safely assumed to be the same as the one for a normal vibrated concrete. In fact due to improvement in homogeneity and denser microstructure, the tensile strength of SCC may be higher than for conventional concrete. Also, due to a less porous microstructure, tensile strength of SCC should be higher than that of CC. This test was carried out on prismatic specimen of size 100mm x 100mm x 500mm specimens were kept as simply supported beam in Universal Testing Machine and single point load was applied till the rupture of beam.

6. EXPERIMENTAL RESULTS

6.1 Fresh properties of SCC

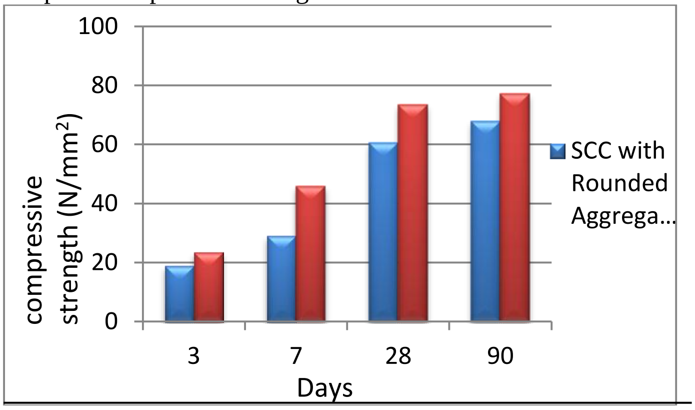
Test	Slump flow (mm)	V- funnel (sec)	L- box ratio
SCC with Rounded Aggregate	700	8.0	0.98
SCC with Angular Aggregate	665	10.09	0.86

Test	Compressive strength (Mpa)				Flexural strength (Mpa)	
Days	3	7	28	90	28	90
SCC with Rounded Aggregate	18.86	29.05	60.66	67.93	9.00	9.45
SCC with Angular Aggregate	23.48	45.81	73.50	77.25	10.73	10.87

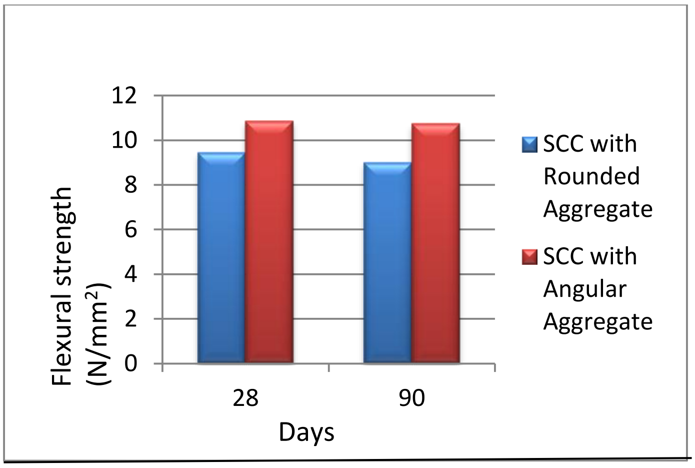
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 09, September-2016

6.2 Strength Properties of SC

Graph1: Compressive strength of concrete cubes



Graph2: Flexural strength of concrete beams



7. RESULT AND DISCUSSION

Fresh Properties

SCC prepared with rounded coarse aggregate has shown better fresh property than SCC with angular coarse aggregate. The slump flow was 5.3% greater, The V-funnel time was 21% less and L-Box ratio was 13.9% greater which showed better flowing ability, passing ability and filling ability of the SCC with rounded shaped aggregate.

Strength Properties

- *Compressive strength-*

The SCC with angular shaped aggregate performed better than SCC with rounded shaped aggregate .When compressive strength concerned, it has produced 1.21 times 28 days strength, 1.57 times 7 days strength, 1.24 times 3 days strength and 1.14 times 90 days strength.

- *Flexural strength-*

The flexural strength is also 1.15 times at 28 days and 1.19 times 90 days strength.

The better strength observed in case of SCC with angular coarse aggregate was due to better bonding, better interlocking and larger surface area available for bonding. The difference in the strength at latter ages was less, may be due to maximum extent of hydration of cement. Hence better bounding of mortar with rounded shaped aggregate as compare to same at earlier age. Hence it can be concluded that rounded shaped coarse aggregate can also produce High strength SCC with

Little difference in the strength as compared to that of angular shaped aggregate.

8. CONCLUSION

Rounded shape coarse aggregate performed better as compared to angular shape coarse aggregate in fresh state and angular shape coarse aggregate have performed better than rounded shape coarse aggregate in hardened state. Hence it is concluded that angular shape coarse aggregate should be preferred over rounded coarse aggregate for production of high strength SCC.

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