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Study on Self Compacting Concrete by Partial Replacement of Coarse Aggregate with Crushed Coconut Shell

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Abstract - Self-compacting concrete (SCC) is a concrete mixture is capable of consolidating under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in sections with congested reinforcement in minimal time. Consumption of large amount of coarse aggregate affects the environment. For the purpose of reducing the consumption of coarse aggregate there is a need for an alternative material to replace coarse aggregate. In this paper an attempt has been made to improve the performance of SCC by partial replacement of coarse aggregate with crushed coconut shell. The mix design for SCC was arrived as per the guidelines of European Federation of National Associations Representing for Concrete (EFNARC). To test the workability of SCC slump cone test, L-box test and V-funnel test were conducted. The fresh and hardened properties of SCC using partial replacement of coarse aggregate with crushed coconut shell were evaluated. The cement content, fine aggregate, fly ash and super plasticiser were kept constant for all concrete mixtures. Four sets of SCC mixtures were prepared with maximum of 10% replacement of coarse aggregate. Compressive strength and Split tensile strength were carried out in this investigation. It was found that a partial replacement of 2.5% coarse aggregate with the coconut shell helped in improving the economy in construction while maintaining the engineering properties of concrete.

Index Terms - SCC – Self Compacting Concrete

1. INTRODUCTION

The SCC concept was first introduced into scientific world in Japan in 1980 by Professor Hajime Okamura from Tokyo University. The Self-Compacting Concrete is a kind of concrete with excellent deformability and good segregation resistance which is able to flow under its own weight and passes freely around obstructions filling every nook and corner of a formwork resulting in rapid rate of concrete placement. Further, to ensure high filling ability and flow without blockage, Self-Compacting Concrete should have lesser coarse aggregate contents and hence high cement content which can increase the cost and temperature during hydration which leads to possible effect on other properties such as creep and shrinkage. In recent days, to enhance the properties of fresh and hardened concrete, an addition like fly-ash is often partially incorporated in place of cement. Further, the use of fly ash in concrete is well established and widely applicable because it is not only economical from cost but it also improves the fresh and hardened properties of concrete. The specific requirement of self-compacting concrete is its capacity for self-compaction, without vibration, in the fresh state. Other performances such as strength and durability should be stablished as for normal concrete.

S Jayasree (2014) et al carried out an experimental study on the effects of crushed concrete aggregates on the fresh and mechanical properties of SCC. K Chinnaraju (2014) et al observed that the recycled coarse aggregates have relatively fine particles than natural coarse aggregates due to the crushing of old concrete. Paratibha Aggarwal (2008) et al presented a procedure for the design of self-compacting concrete mixes based on an experimental investigation. Girish (2010) et al presented the results of an experimental investigation carried out to find out the influence of paste and powder content on self-compacting concrete mixtures. Felekoglu (2005) et al. has done research on effect of w/c ratio on the fresh and hardened properties of SCC.Vishwas P. Kukarni, Sanjay Kumar B. Gaikwad (2013) carried out an experimental study and proposed that coconut shell is compatible with the cement. Arivalagan S (2013) made out an experimental analysis of self-compacting concrete incorporating different range of High-Volumes of Class F Fly Ash.

In India, during the last few years, attempts were made in the laboratories and in the field to develop and use SCC. However, large scale uses have been rare. Some pioneering efforts have been made in Delhi Metro projects in association with L&T. Nuclear power Corporation, Gammon India, Hindustan Construction Company have been made large scale laboratory trials and on the ground Moch up trials. Laboratory studies conducted at SERC Chennai, Indian Institute of Technology at Madras, Roorkee and other places have given enough inputs and confidence to adopt SCC in India. Of all the places, Delhi Metro project have used SCC in large scale for dome construction, tunnel lining, column casting etc. About 10,000m^3 of SCC has been used in as many as forty locations during the year 2004. This is by far the biggest use of SCC in India. . The general objective of this paper is to check the possibility of preparing self-compacting concrete and to find out the potential benefits and drawbacks by using coconut shell as a partial replacement for natural coarse aggregate

2. PROPERTIES OF SCC

SCC has three essential fresh properties: filling ability, passing ability and segregation resistance. Filling ability is the characteristic of SCC to flow under its own weight and to completely fill the formwork. Passing ability is the characteristic of SCC to flow through and around obstacles such as reinforcement and narrow spaces without blocking. Segregation resistance is the characteristic of SCC to remain homogeneous during and after transporting and placing. It is passing ability that distinguishes SCC from other high consistence concrete.

SCC must flow into the intended area without segregation. To achieve a high filling ability, it is necessary to reduce inter-particle friction among solid particles (coarse aggregate, sand and powder) in concrete by using a super plasticiser and a lower coarse aggregate content (Khayat, 1999b; Sonebi and Bartos, 2002) . When SCC is placed in structures with congested reinforcement, it must pass smoothly between the bars without blocking. Blocking results from the interaction among aggregate particles and between aggregate particles and reinforcement. A reduction in coarse aggregate content and lowering the size are both effective in inhibiting blocking. Free water, which cannot attach to the solid particles and moves freely in the concrete, is the main influence on segregation (Ozawa et al., 1990). Segregation which happens during placing is called dynamic segregation. After placing, if coarse aggregate settles and the free water rises causing bleeding, this is called static segregation. Bleeding water reaches the concrete surface or is trapped under obstacles such as coarse aggregate and reinforcement bars which weakens the interfacial zone and results in impaired strength and durability. Enhancement of segregation resistance includes binding extra free water by lower W/P ratio, use of VMA or a high volume of powder, hence providing proper viscosity to ensure homogeneous flow. Limiting the size and content of coarse aggregate are also effective in inhibiting segregation.

Table 1. Requirements for SCC

Property	**Test methods**
Filling ability	Slump flow by Abrams Cone
Passing ability	J - ring, L-box, Fill box
Segregation resistance	V funnel at T5 minutes

3. COMPLEXITIES INVOLVED IN MAKING SCC

Normal strength concrete itself is a complex material. High Strength and high performance concrete with low water/binder ratio adds to the complexity. Making self-compacting concrete, particularly of high strength, adds further to the complexity. Generally self-compacting concrete is used in situations for concrete requiring high strength say over 40MPa upto 100MPa or more. Production of such high strength concrete would require the use of relatively water/binder ratio. Binder generally includes silica fume also. Use of silica fume while increasing the strength reduces the workability to an unacceptable level for self-compacting requirements. To restore the workability or even to have much higher level of workability needed for SCC, a higher dose of super plasticizer could lead to two major problems. Firstly, all the super plasticizers available in the market are not suitable for application at high dosage. Therefore it is important to choose the one that could be used without causing adverse side effect such as excessive retardation, at the same time the one that could retain the slump for sufficiently long time. The super plasticizers based on Naphthalene or Melamine are generally not suitable for self-compacting concrete requiring very high strength. Initial trial for finding the compatibility between super plasticizer and cement, at very low water/binder ratio is also required to be ascertained.

Another point for consideration is that, there is a tendency for using relatively large binder paste volume in order to achieve both high strength and self-compacting properties. From all round performance point of view, the use of a large binder paste volume is undesirable as it would lead to higher heat of hydration, greater shrinkage and creep.

4. EXPERIMENTAL INVESTIGATION

The main objective of the experimental programme is to check the possibility of preparing self-compacting concrete and to find out the potential benefits and drawbacks by using coconut shell as a partial replacement for natural coarse aggregate. The experiment was carried out in two phases.

In the first phase, an appropriate mix proportion for self-compacting concrete was found out, satisfying all the fresh properties of a SCC such as filling ability, passing ability and segregation resistance.

In phase two of the experimental programme, Crushed Coconut Shell (CCS) was added to SCC as a partial replacement for natural coarse aggregate. Tests were done to evaluate the fresh and hardened properties of SCC with 2.5%, 5% and 10% replacements.

4.1. *Materials*

The materials used for the experimental investigation were cement, natural fine aggregate, natural coarse aggregate, super-plasticizer, fly ash, Crushed coconut shell and water. The natural fine aggregate and natural coarse aggregate (NCA) confirmed to IS: 383 – 1970 with the fine aggregate having a gradation curve lying in zone II.

4.1.1. *Cement*

Ordinary Portland Cement of 43 grade conform to the Bureau of Indian Standard specification with specific gravity 2.8 is used. Properties of cement used is given in table 2.

4.1.2. *Fly ash*

Fly ash is a residue from the combustion of pulverized coal collected by mechanical separators, from the fuel gases of thermal plants. The composition varies with type of fuel burnt, load on the boiler and type of separation. These are used to improve quality and durability.The use of fly ash as concrete admixture not only extends technical advantages to the properties of concrete but also contributes to the environmental pollution control. India alone produces about 75 million tons of fly ash per year, the disposal of which has become a serious environmental problem. The effective utilization of fly ash in concrete making is therefore, attracting serious consideration of concrete technologists and government departments. Class F fly ash was used for this experiment of whitish grey colour.

Table 2. Properties of cement

Properties	Value
Standard consistency	38%
Initial Setting time	75 minutes
Final Setting time	210 minutes
Fineness	97.9 %
Specific Gravity	2.8

4.1.3. *Natural Fine Aggregate*

Fine aggregate which are passing through 4.75mm sieve and having specific gravity of 2.6 was used.

4.1.4. *Natural coarse aggregate*

The maximum size of aggregate is generally limited to 20mm. Aggregate of size 10 to 12mm is desirable for structures having congested reinforcement. Wherever possible size of aggregate higher than 20mm could also be used. Well graded cubical or grounded aggregates are desirable. Aggregates should be of uniform quality with respect to shape and grading. In this experimental study particle size between 10mm and 12 mm with a specific gravity of 2.6 was used.

4.1.5. *Admixtures*

The most important admixtures are the super plasticizers (High Range Water Reducers) used with a water reduction greater than 20%. Super plasticizer is a chemical compound used to increase the workability without adding more water i.e. spreads the given water in the concrete throughout the concrete mix resulting to form a uniform mix. Super plasticizer improves better surface expose of aggregates to the cement gel. Super plasticizer acts as a lubricant among the materials. For this experiment CAC Hyper fluid conforming to ASTM C, type F of IS 9103: 1999 was used.

4.1.6. *Water*

This is the least expensive but most important ingredient of concrete. The water which is used for making concrete should be clean and free from harmful impurities such as oil, alkali, acid, etc. Portable water was used for the experiment.

4.1.6. *Coconut shell*

The freshly discarded Coconut shells were collected. The coconut shells were crushed using hammers to a size such that it passes through a 12.5mm sieve and retained on 10 mm sieve. Crushed shells were cleaned to remove fibres, mud etc. from them.

5. 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 fulfill 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.

6. TESTS FOR SELF COMPACTING CONCRETE

It is important to mention that none of the test methods for SCC has yet been standardized and the tests mentioned below are not yet perfected. They are mainly adhoc method which have been devised for SCC. Tests done to check the fresh properties of SCC includes slump flow test, V-Funnel at T5 minutes, L-Box test. The hardened properties of SCC was analysed from tests for compressive strength and split tensile strength.

6.1. *Slump Flow Test*

Slump flow 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 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. Typically, slump flow values of approximately 24 to 30 inches are within the acceptable range; acceptable T50 times range from 2 to 5sec.

6.2. *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. 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 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.

6.3. *V–funnel Test atT5 minutes*

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.

6.4. *Compressive Strength of Concrete*

Compressive strength of concrete is defined as the load, which causes the failure of a standard specimen divided by the area of cross section in uniaxial compression under a given rate of loading. The test of compressive strength was made on 150mm size cubes. Application of load should be 300KN per minute and can be controlled by load rate control knob. Ultimate load is noted for each specimen.

6.5 *Split Tensile Strength*

A concrete cylinder of size 150mm diameter and 300mm height is subjected to the action of the compressive force along two opposite edges, by applying 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.

7. WORKABILITY REQUIREMENTS FOR THE FRESH SCC

The workability requirements to be fulfilled at the time of placing is given in Table 3. Any changes in workability during transport and other delays should be taken in to account in production.

Table 3. Acceptance Criteria for SCC

Sl No	**Method**	**Unit**	**Range of Values**	
			Min	**Max**
1	Slump flow test	mm	650	800
2	V funnel test	Sec	8	12
3	L box test	H2/H1	0.8	1.0

Table 4. Mix Proportion for Trial Mixes

Trial Mix	**Cement (kg/m^3)**	**Fly Ash(kg/m^3)**	**Fine Aggregate (kg/m^3)**	**Coarse Aggregte (kg/m^3)**	**Water (L)**	**Super Plasticizer (%)**	**L – box (sec)**	**V – funnel (sec)**	**Slump (mm)**
1	781	156.5	1140	742.2	15	2	0.55	129	300
2	465	93.8	922	754	14	1	0.8	53	350
3	465	91.7	916.6	1083	8	2	0.75	112	297
4	465	91.6	916.6	1083	8	3	0.8	46	375
5	465	91.7	916.6	1083	9.33	3	1	27	425
6	465	116.7	916.6	1015	11.14	3	9	64	570
7	465	91.66	916.6	1015	8	2	0.85	47	623
8	375	112	1000	1000	10.6	4	1	32	682
9	375	150	937.5	937.5	9.6	7	0.87	40	598
10	375	150	937.5	937.5	8.53	7	1	43	610
11	375	150	93.75	937.5	10.1	7	1	38	653
12	375	152.5	1000	1000	10.6	5	1	15	680
13	375	116.7	916.7	1000	1105	3	0.92	25	575
SCC	375	150	937.5	937.5	8	6	1	9	720

Table 5. Mix Proportion for Experimental Study

Mix	Cement (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	CCS (kg/m^3)	Fly ash (kg/m^3)	SP (%)	Water (L)
SCC	375	937.5	937.5	0	150	6	8
2.5 %	375	937.5	914.06	23.44	150	6	8
5 %	375	937.5	890.62	46.88	150	6	8
10 %	375	937.5	843.75	93.7	150	6	8

Table 6. Fresh Properties of SCC with CCS

Mix	Slump (mm)	EFNRC		L-Box (sec)	EFNRC		V – funnel (sec)	EFNRC	
		Min	Max		Min	Max		Min	Max
CCS 0%	720	650	800	1	0.8	1	9	8	15
CCS 2.5%	700			1			14		
CCS 5%	730			1			11		
CCS 10%	695			1			13		

8. MIX PROPORTIONING

Recommendations on the design and applications of SCC in construction have been developed by the European Federation of National Trade Associations (EFNARC 2002).

The SCC design mix calculations were carried out as per the Japanese Method which strictly adheres to the EFNARC recommendations. In this method, coarse and fine aggregate contents were initially fixed so that self-compactability is achieved by adjusting the water powder ratio and super-plasticizer dosage. SCC trial mixes were prepared with varying percentages of fly ash, super plasticizer, natural coarse and fine aggregates and water to obtain SCC of M20 grade. The percentage of fly ash was varied from 20% to 40% of total powder content. Also the super-plasticizer content was varied from 1% to 7% of total powder. For each prepared mix, the workability was assessed using Slump cone test, V Funnel test and L-Box test.

The material quantities and workability characteristics of the trial mixes are given in Table 4.

Fourteen trial tests were performed with varying percentages of super plasticizer and fly ash. SCC was obtained after thirteen trial mixes. The mix ratio adopted for the second phase of experiment is 1: 2.5: 2.5.

9. RESULTS AND DISCUSSIONS

The freshly discarded coconut shells were collected. The coconut shells were crushed using hammers to a size such that it passes through a 12.5 mm sieve and retained on 10mm sieve. The material was used to partially replace coarse aggregate with coconut shells. SCC mixes were prepared by replacing natural coarse aggregate with 2.5%, 5% and 10% of Crushed Coconut Shell (CCS) by weight. Tests were repeated to assess the fresh and hardened properties of SCC with replaced aggregate ratio. Table 5 provides mix proportion values for each replacement percentage of natural coarse aggregate.

Table 6 gives the workability measurements for each replacement percentage. As it is evident, the basic requirements of high flow ability and segregation resistance, as specified by guidelines on self-compacting concrete by EFNARC, are satisfied. The workability values are maintained by adding suitable quantities of super plasticizers.

Cubes and cylinders were prepared for varying replacement percentages to evaluate the compressive strength and split tensile strength. For each concrete mixture, nine number of 150mm cubes were cast for the determination of compressive strength, nine numbers of 150mm 300mm cylinder were cast for the determination of split tensile strength. A comparative study on properties of crushed coconut shell in self compacting concrete for M20 grade of concrete was studied. To determine the properties of concrete for each mix on various sizes of specimen tests were conducted at different ages of curing according to the procedures given in Indian Standard Code of practices. Results are presented in Table 7.Cube compressive strength of specimens was tested after 7, 14 and 28 days of concrete.

Table 7. Compressive Strength of Cube Specimens

% replaced	**7 day (N/mm^2)**	**14 day (N/mm^2)**	**28 day (N/mm^2)**
0	14.44	19.48	21.65
2.5	13.38	18.05	20.06
5	12.53	16.91	18.79
10	9.04	12.2	13.56

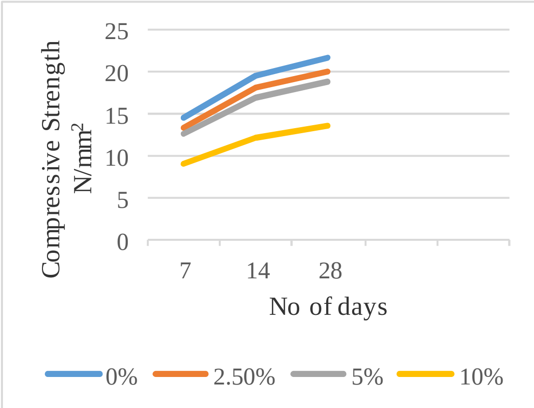

Fig 1. Compressive Strength at Various Ages

From Fig1, it was found out that compressive strength decreases with increase of crushed coconut shell. 2.5% can be chosen as the optimum which yielded 20.06 N/mm^2 at the end of 28 days of curing.

Split tensile strength test was carried out with 0%, 2.5%, 5% and 10% replacement of natural coarse aggregate with crushed coconut shell for M20 grade of concrete. The tests were tests were conducted at different ages of curing according to the procedures given in Indian Standard Code of practices. Split tests of carried out after 7, 14 and 28 days of curing. The results are tabulated in Table 8.

From Fig 2. it was observed that the split tensile strength decreases with increasing percentage of crushed coconut shell. 2.5% replacement gives maximum split tensile value. Hence it can be treated as the optimum value.

Table 8. Split Tensile Strength of Cylinder Specimens

% replaced	**7 day (N/mm^2)**	**14 day (N/mm^2)**	**28 day (N/mm^2)**
0	2.43	2.78	3.9
2.5	1.48	1.76	3.43
5	1.17	1.3	2.9
10	0.79	1.02	1.09

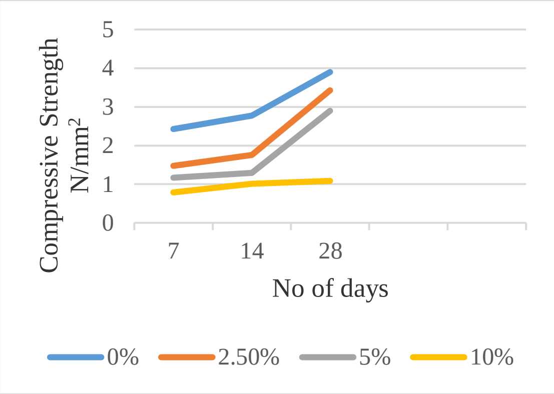

Fig 2. Split Tensile Strength at Various Ages

10. CONCLUSION

Self-Compacting Concrete has found its place in the modern day construction and used in the construction of many structures worldwide. Some of these structures include Burj-Dubai, Arlanda Airport Control Tower and Delhi-metro. SCC has achieved its popularity due to its economy, uniform quality and scope for its improvement.

The main objective of this paper was to determine a mix design for Self-Compacting Concrete (SCC) satisfying the necessary requirements of good concrete and to partially replace the coarse aggregate with coconut shell. The first phase helped to find a good mix design for SCC (1 : 2.5 : 2.5) which satisfy the basic requirement of SCC such as flow, segregation resistance, and filling ability by conducting tests like slump flow test, V-funnel test and L-box test. In the second phase it was found that a nominal amount of coconut shell that could replace the coarse aggregate (i.e. 2.5%) by trying out various percentage of coconut shell replacement. From this data it is evident that the two main objectives were achieved.

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