Effect of different sizes of coarse aggregate on the properties of NCC and SCC

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ABSTRACT

Self-Compacting concrete (SCC) needs no external vibration and compacts fully under its self weight. This paper describes experimental work carried out to develop SCC and to study the effect of different sizes (i.e., 20mm; 16mm; 12.5mm and 10mm) of coarse aggregate (C.A) on the properties of SCC. Eight mixes were investigated for M30 grade concrete. The water-powder ratio was kept fixed throughout the SCC mixes. The superplasticizer (S.P)(Structuro 100) and viscosity modifying admixture (V.M.A)(Structo 480) dosages was determined from mortar trails. To achieve self-compacting properties, successive replacement of C.A by fine aggregate was adapted. Slump flow test, V-funnel test, J-ring test and L-box test on fresh concrete were carried out as per EFNARC guidelines. The compressive strength, split tensile strength and flexural strength of the concrete after 7, 28 &56 days curing were also investigated. The test results showed how Self-Compacting properties were achieved as different sizes of C.A.

Keywords: **Self-compacting concrete, fly ash, coarse aggregate, workability, strength.**

1. Introduction

There has been an increase in using SCC in recent years and a number of papers have been published [1-6]. SCC was first developed in Japan in the late nineteen eighties to be used in the construction of skyscrapers [1]. The introduction of SCC represents major technological advances, which leads to a better quality concrete and an efficient construction process [7]. SCC allows the construction of more slender building elements and more complicated and interesting shapes [8]. The production of SCC allows the pumping of concrete to a great height and the flow through congested reinforcing bars without the use of compaction other than the concrete self-weight. As a result, the use of SCC can lead to a reduction in construction time, labour cost and noise level on the construction site [7, 9].

The use of chemical admixture sis always necessary when producing SCC in order to increase the workability and reduce segregation. The content of coarse aggregate and the water to binder ratio in SCC are lower than those of normal concrete. Therefore SCC contains large amounts of fine particles such as, blast-furnace slag, fly ash and lime powder in order to avoid gravity segregation of larger particles in the fresh mix [10-12].

The aggregate size, shape and surfase texture plays a vital role in the design and performance of concrete mixes. The aggregate size has a direct effect on the density, voids, strength, workability etc., of the concrete mixes. it also influence the concrete mix properties such as powder content, air voids, voids filled with powder, stability, flow values durability, fatigue life etc. it may therefore be mentioned that almost all the mix properties depend on the size and proportions of coarse and fine aggregate in the mix. The influence of these properties on workability of concrete has been duly incorporated in various codes of practice on concrete mix proportioning such as BIS [13], ACI [14], etc. However, these codes are silent about the influence of aggregate properties on the strength of concrete. The assumption that the strength of concrete is governed by the free water cement ratio irrespective of the type of aggregate seems to be on over simplification as size, shape and surface texture of aggregate bound to influence the strength of concrete. This paper presents the results on the experimental investigation carried out to study the influence of size of C.A on strength of concrete.

2. Materials

2.1. Cement

The cement used in all mixtures was commercially available Ordinary Portland cement (OPC) of 53 grade manufactured by priya company confirming to IS: 12269 was used in this study. The specific gravity of the cement was 3.12, the initial and final setting times were found as 90minutes and 210 minutes respectively.

2.2. Fine aggregate

Locally available Godavari river sand passing through 4.75mm IS sieve was used. The specific gravity of fine aggregate was 2.60 and its fineness modulus is 2.59. The loose and compacted bulk density values of sand are 1607 and 1688 kg/m^3 respectively.

2.3. Coarse aggregate

Crushed granite C.A available from local sources has been used. The different sizes (20mm, 16mm, 12.5mm and 10mm) of C.A are used and their Properties are given in Table: 1.

Table: 1 Properties of Coarse aggregate

S. No	property	Size of the C.A(mm)			
		20	16	12.5	10
1.	Passing through IS Sieve,	20	16	12.5	10
2.	Retained on IS Sieve,	16	12.5	10	4.75
3.	Specific gravity	2.78	2.77	2.76	2.74
4.	Loose density(kg/m^3)	1363	1393	1437	1452
5.	Compacted density(kg/m^3)	1540	1570	1585	1600
6.	Fineness Modulus	7	6	6	5
7.	Water absorption (%)	0.42	0.45	0.46	0.50

2.4. Fly ash

Fly ash obtained from Vijayawada thermal power plant (VTPS), Vijayawada, A.P state was used in this study. Chemical analysis of fly ash is given in Table: 2. The fly ash had a relatively low specific gravity and fineness modulus of 1.975 and 1.195 respectively.

Table: 2 Chemical Analysis of Fly Ash

S.No	Property	Formula	% Content
1.	Silicon Dioxide	Sio_2	59.04
2.	Aluminum Oxide	Al_2O_3	34.08
3.	Iron Oxide	Fe_2O_3	2.0
4.	Lime	Cao	0.22
5.	Sulphur Trioxide	SO_3	0.05
6.	Magnesium Oxide	Mgo	0.43
7.	Alakalies	NA_2O	0.5
8.	Alakalies	K_2O	0.76
9.	Loss of ignition	LOI	0.63

2.5. Chemical admixtures

A polycarboxylic type superplasticizer (SP) (Structuro 100) was used in all concrete mixtures. In addition to the SP, a viscosity modifying admixture (VMA) (Structuro 480) was also used. The properties of both admixtures, as provided by their manufacturers, are given in Table: 3.

Table: 3 properties of chemical admixture

Chemical admixture	Specific gravity	pH	Colour	Dosage (l/m^3)	Main component
SP	1.01	6.3	opaque	1 to 4	Polycarboxylic ether
VMA	1.06	6.5	Light yellow	0.5 to 2	Aqueous dispersion of microscopic silica

EXPERIMENTAL WORK

3.1. Mix proportions

A total of eight mixes that were employed to examine the properties of NCC and SCC with different sizes of C.A (ie 20mm 16mm 12.5mm &10mm) properties investigated were, Slump flow test, V-funnel test, J-ring test and L-box test on fresh concrete were carried out as per EFNARC guidelines. The compressive strength, split tensile strength and flexural strength of the concrete after 7, 28 &56 days curing. For all the SCC mixes, the total amount of binder (cement +fly ash), the amount of cement, the amount of fly ash and the amount of water were all kept constant. Therefore, the water/powder ratio (w/p) was kept constant at 0.32.chemical admixture in different quantities was added to the mix until the SCC characteristics were obtained. Details of mixes are given in Table: 4.

Table: 4 Mix Proportions

S.No	Mix ID	Size of C.A	Fly ash (%)	Cement (kg/m^3)	Fly ash (kg/m^3)	Total powder (kg/m^3)	Water (l/m^3)	w/b-Ratio	F.A (kg/m^3)	C.A (kg/m^3)	SP (l/m^3)	VMA (l/m^3)
1.	NCC20	20	-	421	-	421	189.45	0.45	545	1239	-	-
2.	NCC16	16	-	425	-	425	191.25	0.45	542	1228	-	-
3.	NCC12.5	12.5	-	426	-	426	191.7	0.45	542	1223	-	-
4.	NCC10	10	-	429	-	429	193.05	0.45	540	1215	-	-
5.	SCC20	20	50	300	300	600	192	0.32	717	767	1.50	0.42
6.	SCC16	16	50	300	300	600	192	0.32	717	764	1.50	0.48
7.	SCC12.5	12.5	50	300	300	600	192	0.32	717	761	1.50	0.60
8.	SCC10	10	50	300	300	600	192	0.32	717	756	1.50	0.66

3.2. Preparation and casting of test specimens

The following mixing sequence was arrived after several trials optimizing the workability. All the ingredients were first mixed in dry condition in the concrete mixer for one minute. Then 70% of calculated amount of water was added to the dry mix and mixed thoroughly for one minute. The remaining 30% of water was mixed with the super-plasticizer and viscosity-modifying agent and was poured into the mixer and mixed for three minutes. At this stage, 20% of the water mixed with superplasticizer (struturo100) was poured into mixer and mixed for two minutes. Then, 10% of water mixed with viscosity modifying agent (structuro 480) was poured into the mixer and mixed for one minute. Later required quantities of steel fiber were sprinkled over the concrete mix and mixed for one minute to get a uniform mix. Thus, the total mixing time was 7 minutes.

After the mixing procedure was completed, tests were conducted on the fresh concrete to determine slump flow time and diameter, J-Ring test, L-Box ratio test, and V-funnel flow time no. Segregation and bleeding was observed during the slump flow test for any of the mixes. From each concrete mix, twelve 150-mm cubes, nine cylinders 150 mm diameter and 300 mm height and nine beams of size 100x100x500 mm were cast. All specimens were cast in one layer without any compaction. The cubes were used for the compressive strength, the cylinders were used for the splitting tensile strength and beams were used for the flexural strength tests. After demoulding, all specimens were placed in a curing tank at room temperature.

3.3. Tests on fresh concrete

Deformability and viscosity of fresh concrete is evaluated through the measurement of slump flow time and diameter, J-Ring test, L-Box ratio test and V-funnel flow time test (Fig.1). The slump flow is used to assess the horizontal free flow (deformability) of SCC in the absence of obstructions. The procedure for the slump flow test and the commonly used slump test are almost identical. In the slump test, the change in height between the cone and the spread concrete is measured, whereas in the slump flow test the diameter of the spread is measured as the slump flow diameter (D). According to Nagataki and Fujiwara [15], a slump flow diameter ranging from 500 to 700 mm is considered as the slump required for a concrete to be classified as SCC. According to Specification and Guidelines for SCC prepared by EFNARC [16] (European Federation of National Trade Associations), a slump flow diameter ranging from 650 to 800 mm can be accepted for SCC. In the slump flow test concrete's ability to flow and its segregation resistance can also be measured. To measure these properties, the time it takes for the concrete to reach a 500-mm spread circle and any segregation border between the aggregates and mortar around the edge of spread are recorded. EFNARC [16] suggests a slump flow time (t_{500mm}) of 2-5s for a satisfactory SCC.

Fig: 1. workability test on the SCC

In addition to the slump flow test, J-Ring test, L-Box test and V-funnel test, were also conducted to assess the flow ability, passing ability and stability of the SCC. The L-box ratio was in the range of 0.80-1.0, the J-ring test values were in the range of 0-10mm. The V-funnel is filled completely with concrete and the bottom outlet is opened, allowing the concrete to flow. The V-funnel flow time is the elapsed time in seconds between the opening of the bottom outlet and the time when the light becomes visible from the bottom, when observed from the top. Good flowable and stable concrete would consume short time to flow out. According to Khayat [17], flow times were in the range of 6-12sec. is recommended for a concrete to qualify as a SCC. According to EFNARC [16], time ranging from 6 to 12 sec is considered adequate for a SCC. Details of Fresh Properties of SCC mixes are given in Table: 5.

Table: 5 Fresh Properties of Self Compacting Concrete

S.No	Mix ID	Size of C.A(mm)	Slump flow 65-85cm	T_{50cm}Slump 2-5 s	V-Funnel 6-12 s	L-Box Ratio 0.8-1.0	J-Ring 0-10mm
1.	SCC20	20	650	5	12	0.80	10
2.	SCC16	16	670	4.2	11.5	0.85	9
3.	SCC12.5	12.5	710	3.6	10	0.90	8.5
4.	SCC10	10	725	3	9.3	0.92	8

4. Results and discussion

4.1. Fresh concrete properties

SCC contains high fine aggregate and lower C.A when compared to NCC and also high range superplasticiser and VMA to give stability and fluidity of the concrete mix. The need of amount of chemical admixtures (VMA) increases with the decrease of size of C.A. The quantity of VMA used for concrete with 20mm CA (0.42 kg/m^3) is lower than the quantity of VMA used for concrete with 10 mm CA (0.66 kg/ m^3).

Segregation: It is observed that as the size of C.A increases, the tendency of the mix to segregate increases. The same is observed in L-Box Test and J-Ring Test. The ratio of H_2/H_1 for 20mm size CA is lower 0.80 and reaches 0.92 for 10mm size of CA. If this value reaches 1.0 exhibits no segregation.

Flowing ability : It is observed that flowing ability of concrete made with 20mm size of CA is lower than the concrete made with 10mm size of CA.

4.2. Hardened concrete properties

The results of hardened concrete tests are presented in Table:6, which included the 7d, 28d, and 56d compressive strength, split tensile strength and flexural strength tests. To evaluate the effect of different size of

C.A of the hardened properties of SCC, the 56d properties are normalized with respect to the Control NCC mixture and the results are presented in Fig. 2,3, 4. As seen from those figures, the most significant changes were observed on the compressive strength, splitting tensile strength and later on flexural strength at 56d.

Substitution of fly ash based SCC mixes (ie SCC20, SCC16, SCC12.5, and SCC10) resulted in lower compressive, split tensile and flexural strengths at 7d, and 28d, when compared to NCC mixes (ieNCC20, NCC16, NCC12.5 and NCC10). The reduction in compressive strength was 8.09%, 7.23%, 10.18%, 7.15% at 7d, 5.01%, 4.89%, 5.37%,4.40% at 28d. The reduction in split tensile strength was 7.54% ,5.04%, 8.40%, 10.24%, at 7d, and 5.30%, 3.40%, 6.38%, 7.86%,at 28d. The reduction in flexural strength was 8.96%,6.52%,7.33%,6.12%, at 7d, and 3.43%,2.78%,3.99%,4.32%,at 28d. This reduction could be attributed to the low pozzolanic activity of the fly ash. But the increase in compressive strength was 1.87%,3.59%,3.61%,2.32%,at56d,splittensilestrengthwas 4.10%,1.79%,3.29%,1.73%, at 56d and flexural strength was 1.69%,3.56%,5.89%,4.15% at 56d.

Size of the C.A inclusion did not significantly affect the measured mechanical properties. From Table: 6, it may be noted that maximum strength, in general, improved as the size of the C.A content increases from 10 to 20mm. However, only marginal increase is noticed in the easy of ultimate strength. On the other hand maximum compressive, split tensile and flexural strength is found to increase markedly and maximum increase is about 3.59%, 4.10% and 5.89% at 56d in the case of specimen with SCC.

It is observed that from the Table:6 and Fig.2,3,4. the compressive strength, split tensile strength and flexural strengths increases with the increased size of C.A and observed as maximum at 20mm size of C.A when compared to 16mm, 12.5mm, 10mm size at all ages of concrete i.e. 7d, 28,and 56 d.

The rate of attaining the strengths at the ages of 7d and 28 d of NCC are greater than the SCC. But at the age of 56 d SCC attains higher strengths than NCC. So, it is observed that the SCC shows higher performance in attaining strengths on longer duration.

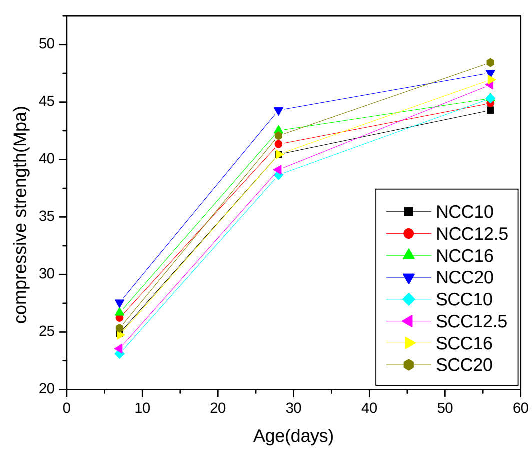

Fig.2.Compressive Strength (Mpa)

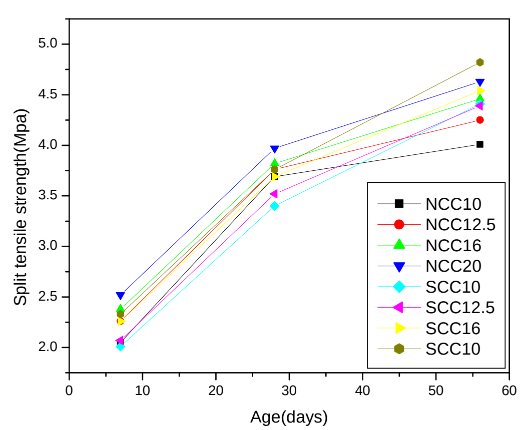

Fig.3.Split tensile Strength (Mpa)

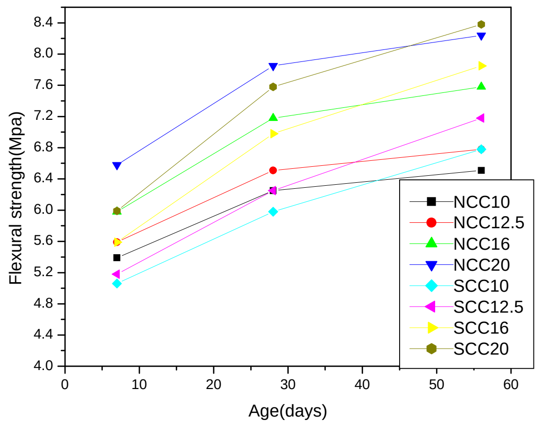

Fig.4.Flexural Strength (Mpa)

Table: 6 Hardened Concrete Properties

S.No	Mix ID	Compressive strength (Mpa)			Split tensile strength (Mpa)			Flexural strength(Mpa)		
		7d	28d	56d	7d	28d	56d	7d	28d	56d
1.	NCC20	27.56	44.29	47.55	2.52	3.97	4.63	6.58	7.85	8.24
2.	NCC16	26.67	42.52	45.32	2.38	3.82	4.46	5.98	7.18	7.58
3.	NCC12.5	26.22	41.33	44.89	2.26	3.76	4.25	5.59	6.51	6.78
4.	NCC10	24.89	40.44	44.29	2.05	3.69	4.01	5.39	6.25	6.51
5.	SCC20	25.33	42.07	48.44	2.33	3.76	4.82	5.99	7.58	8.38
6.	SCC16	24.74	40.44	46.95	2.26	3.69	4.54	5.59	6.98	7.85
7.	SCC12.5	23.55	39.11	46.51	2.07	3.52	4.39	5.18	6.25	7.18
8.	SCC10	23.11	38.66	45.32	1.84	3.40	4.11	5.06	5.98	6.78

Conclusions:

The following conclusions are drawn from the test results and discussions of this investigation

1. The fresh properties of SCC reduces with increase in size of C.A.
2. The Compressive strength, Split tensile strength and flexural strength of NCC and SCC are maximum at 20 mm size of C.A used in the mix. The increase in strength is directly proportional to the size of C.A.
3. As compare with conventional concrete the SCC gives the higher strengths on longer duration.
4. SCC mix requires high powder content, lesser quantity of coarse aggregate, high range superplasticizer and VMA to give stability and fluidity of the concrete mix.
5. SCC fills the formwork and encapsulates the reinforcements without needing vibration, to achieve compaction only through the action of gravity and gives an excellent surface finish.
6. SCC can be obtained for widely differing flyash contents or cement contents as long as the paste volume constituted by the water cement ratio is kept constant.
7. The gain in strength with ages was SCC. The rate of strength gain with age increased for SCC after 28 days.
8. As the size of C.A increases the tendency of the mix to segregate increases.
9. SCC properties can be achieved even for a very high percentage of flyash content. (i.e. up to 50%)

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