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Effect of Size of Aggregate on Self compacting Concrete M30 Grade

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Abstract
Concrete is a versatile widely used construction material. Ever since concrete has been accepted as a material for construction, researchers have been trying to improve its quality and enhance its performance. Recent changes in construction industry demand improved durability of structures. There is a methodological shift in the concrete design from a strength-based concept to a performance based design. At present there is a large emphasis on performance aspect of concrete. One such thought has lead to the development of Self Compacting Concrete (SCC). It is considered as "the most revolutionary development in concrete construction". SCC is a new kind of High Performance Concrete (HPC) with excellent deformability and segregation resistance. It can flow through and fill the gaps of reinforcement and corners of moulds without any need for vibration and compaction during the placing process.
Keywords: *Self compacting concrete, M30 grade, concrete, aggregate, SCC.*

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I. INTRODUCTION

The versatility and the application of concrete in the construction industry need not be emphasized. Research on normal and high strength concrete has been on the agenda for more than two decades. As per IS: 4562000 [Code of Practice for Plain and Reinforced Concrete], concretes ranging 25 – 55 MPa are called standard concretes while those above 55 MPa can be termed as high strength concrete. Concretes above 120/150 MPa are called ultra-high strength concrete. High strength concrete has numerous applications worldwide in tall buildings, bridges with long span and buildings in aggressive environments. Building elements made of high strength concrete are usually densely reinforced. This congestion of reinforcement leads to serious problems while concreting. Densely reinforced concrete problems can be solved by using concrete that can be easily placed and spread in between the congested reinforced concrete elements. A highly homogeneous, well spread and dense concrete can be ensured using such a type of concrete.

Self-compacting concrete (SCC) is a concrete, which flows and compacts only under gravity. It fills the mold completely without any defects. Usually, self-compacting concretes have compressive strengths in the range of 60-100 N/mm2. However, lower grades can also be obtained and used depending on the requirement. SCC was originally developed at the University of Tokyo in Japan with the help of leading concrete contractors during 1980's to be mainly used for highly congested reinforced structures in seismic regions. As durability of concrete structures was 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. The development of SCC was first reported in 1989.

SCC is a new kind of High-Performance Concrete (HPC) which has an excellent deformability and segregation resistance. By name it can be defined as a concrete, which can flow through and fill the gaps of reinforcement and corners of the molds without any need for external vibration. SCC compacts itself due to its self-weight and de-aerates almost completely while flowing in the formwork. 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 formwork without vibration. Since its inception, it has been widely used in large construction works or projects in Japan. Recently, this concrete has gained wide use for different applications and structural configurations across the world.

High strength concrete can be produced with normal concrete. But these concretes cannot flow freely by themselves, to pack every corner of molds and all gaps of reinforcement. High strength concrete based elements require thorough compaction and vibration in the construction process.

SCC has more favorable characteristics such as high fluidity, good segregation resistance and distinctive self-compacting ability without any need for external or internal vibration during the placing process. It can be compacted into every corner of formwork purely by means of its own weight without any segregation. Hence, it reduces the risk of honey combing of concrete.

Resistance to segregation is maintaining homogeneity throughout mixing, transportation and casting. The dynamic stability refers to the resistance to segregation during placement. The static stability refers to the resistance to bleeding, segregation and surface settlement after casting.

1.1.1 Constituents of SCC

Coarse aggregate:

The coarse aggregate chosen for Self Compacting Concrete should be well graded and smaller in terms of the maximum size than that used for conventionally vibrated concrete (NC). For typical conventional concrete (NC) the coarse aggregate size may be 20 mm and even more in general. The rounded aggregates and smaller size of aggregate particles improves the Flowability, deformability and segregate resistance of SCC. The gradation is an important factor in choosing a coarse aggregate, where, highly congested reinforcement patterns are used and where, very small dimensional elements are to be produced. In case of conventional concrete (NC), the size of the coarse aggregate depends upon the type of the construction. Like in case of conventional concrete (NC), size of aggregate has a key note to play in SCC designs also. Hence, studies are needed to assess the maximum size of aggregate for a particular grade of concrete. Usually, the maximum size of the coarse aggregate used in production of SCC, ranges approximately between 10mm and 20mm.

Fine Aggregate:

All normal river sands are suitable for SCC. Both crushed and rounded sands can be used. Siliceous and calcareous sands can be used for production of SCC. The number of fines less than 0.125mm is to be considered as powder which is very important for the rheology of SCC. A minimum number of fines must be maintained to avoid segregation. The number of fines has a very significant effect on SCC mix proportions. Fine sand requires more water and Super Plasticizer (SP), but less filler than coarse sand. The SP dosage, water content and cement/filler content could adjusted by treating the fines (>150 um) in sand as part of the fille.

Cement:

All types of cements conforming to Bureau of Indian standards are suitable as per Indian conditions. Selection of the type of the cement is made depending on the overall requirements of SCC such as strength, durability etc. The cement content can be 350 – 450 kg/m3. The usage of cement more than 500 kg/m3 may increase the shrinkage in the hardened state of concrete, whereas the quantity less than 350 kg/m3 may decrease the durability of SCC. Hence, cement content shall be judged properly. Less than 350 kg/m3 may also be used with the inclusion of other fine fillers such as fly ash, Ground Granulated Blast Furnace Slag (GGBS) and rice husk ash.

Water:

Potable water shall be used for the production of SCC. In case of conventional concretes (NC), the water is proportionate only with the cement content. It is called as the water-cement ratio. This influences the mix and thereby workability. But, in the case of SCC, instead of water-cement ratio the term water binder-ratio will be used. This means the content of water mixed in the SCC is proportionate to the total binders such as cement, fly ash etc.

Mineral admixtures:

Mineral admixtures are added to concrete as a part of the cementitious material. They may be used as an addition to or as a part replacement of Portland cement in concrete. This depends on the properties of materials and the desired effect of concrete. Optimum number of mineral admixtures are used to improve specific concrete properties such as workability and strength.

Fly Ash:

Fly ash or pulverized fuel-ash is a residue from the combustion of pulverized coal collected by mechanical separators, from the fuel gases of thermal plants. The composition of fly ash varies with type of fuel burnt, load on the boiler and type of separation. Fly ash material solidifies while suspended in the exhaust gasses and

is collected by electrostatic precipitators or filter bags. Fly Ash consists mostly of silicon dioxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3), and is hence a suitable source of aluminium and silicon for geopolymers. They are also pozzolanic in nature and react with calcium hydroxide and alkali to form Calcium Silicate Hydrates (C – S – H).
The average particle size of fly ash is about 20 microns, which is similar to the average particle size of Portland cement. Particles below 10 microns provide the early strength in concrete, while particles between 10 and 45 microns react more slowly. Fig.1.1 shows the SEM micrograph of fly ash. particles. The specific gravity of fly ash particles ranges between 2.0 to 2.4 depending on the source of coal. The fineness of fly ash is in the range of 250 - 600 m2/kg.

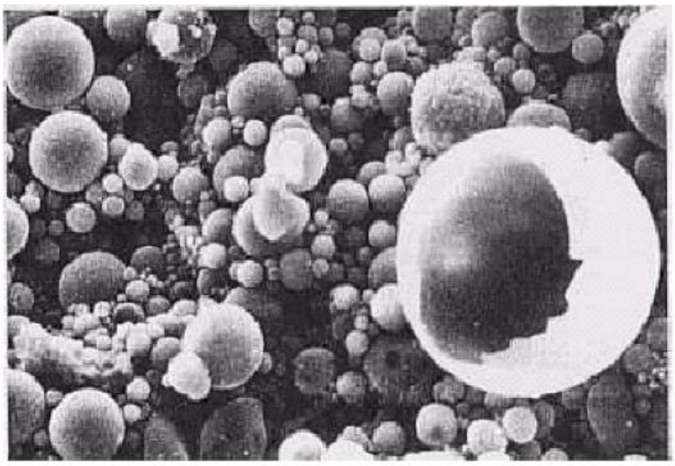


Figure 1: SEM micrograph of fly ash particles

Chemical admixtures:

Chemical admixtures are used in Self Compacting Concrete as ingredients which can be added to the concrete mixture immediately before or during mixing. The use of chemical admixtures such as water reducers, retarders, high-range water reducers or Super Plasticizers (SP), and Viscosity Modifying Admixtures (VMA) is necessary in order to improve the fundamental characteristics of fresh and hardened concrete. They help in the efficient use of large amount of cementitious material in high strength and self-compacting concretes so as to obtain the lowest water to cementing materials ratio.

Super Plasticizer:

Generally, in order to increase the workability, the water content is to be increased provided a corresponding quantity of cement is also added to keep the water cement ratio constant, so that the strength remains the same. Portland cement, being in fine state, has a tendency to flocculate in wet concrete. This flocculation entraps certain amount of water used in the mix and there by all the water is not freely available to increase the fluidity of mix. On the other hand, to avoid the use of excess quantity of water and cement, SP is used to increase the fluidity of the mix and improve the workability of concrete. When plasticizers are used, they get absorbed on cement particles. The absorption of charged polymer on cement particle creates particle to particle repulsive forces, which over come the attractive forces. This repulsive force is called zeta potential which depends on the base, solid contents and quality of super plasticizer used.

Viscosity Modifying Agent:
The use of Viscosity Modifying Agent (VMA) gives higher possibilities of controlling segregation in SCC when the amount of powder is limited. This
admixture helps to maintain very good homogeneity and also reduces the tendency to segregate. The VMA is incorporated to enhance the yield value and viscosity of fluid mixture.

II. EXPERIMENTATION

Wide spread applications of SCC have been restricted due to lack of standard mix design procedure and testing methods. It is pertinent to mention that only features of SCC have been included in Indian Standard Code of practice for plain and reinforced concrete (fourth revision), [2000]. Slump flow test, L-box test, V-funnel test, U-box test, Orimet test & GTM Screen test are recommended by EFNARC [European Federation of Producers and Applicators of Specialist Products for Structures, May 2005] for determining the properties of SCC in fresh state.

The experimental program consisted of casting and testing specimens for arriving at the maximum size of aggregate. M30 grade of concrete is considered in this study. In the first stage the effective maximum size of aggregate for M30 grade of concrete was arrived. Nan Su method of mix design [2001] was adopted to arrive at the suitable mix proportions. The mix proportion for M30 grade was arrived, taking the different sizes of aggregate into consideration. The effective size of aggregate was arrived for M30 grade of concrete, based on the mechanical properties and fresh properties of SCC. A total of 27 cubes of standard size 150 mm x 150 mm x 150 mm, 27 prisms of standard size 100 mm x 100 mm x 500 mm and 27 cylinders of 150 mm diameter and 300 mm height were cast for determining the compressive strength, flexural strength and split tensile strength respectively. The parameters of the study thus included size of aggregate and age of curing for satisfying the fresh properties of SCC as per EFNARC specifications [2005] based on a number of trials.

The present investigation is mainly directed towards developing a mix with good SCC, with different sizes of coarse aggregate and for M30 grade of concrete. The details of fresh properties and hardened properties of SCC with different sizes of coarse aggregate and different are discussed in detail in Chapter – 4. The details of the materials, mix proportioning, specimen preparation and test methodology are briefly presented in this chapter.

Materials:

The materials used in the experimental investigation are locally available cement, sand, coarse aggregate, mineral and chemical admixtures. The chemicals used in the present investigation are of commercial grade.

Cement:

Ordinary Portland cement of 53 grade [IS: 12269-1987, Specifications for 53 Grade Ordinary Portland cement] has been used in the study. It was procured from a single source and stored as per IS: 4032 – 1977. Care has been taken to ensure that the cement of same company and same grade is used throughout the investigation. The cement thus procured was tested for physical properties in accordance with the IS: 12269 – 1987.

Table 1 shows the physical characteristics of cement used, tested in accordance with IS: 4031-1988 [Methods of physical tests for hydraulic cement].

Table 1: Physical properties of Ordinary Portland Cement

S. No	Property	Test Method	Test Results
1.	Normal Consistency	Vicat Apparatus (IS: 4031 Part - 4)	30%
2.	Specific gravity	Sp. Gr bottle (IS:4031 Part - 4)	3.09
3.	Initial settingtime & Final settingtime	Vicat Apparatus (IS: 4031 Part - 4)	96 minutes & 207 Minutes
4.	Fineness	Sieve test on sieve no.9 (IS: 4031 Part – 1)	1.3%
5.	Soundness	Le-Chatlier method (IS: 4031 Part – 3)	2 mm (Not more than 10mm)

Fine Aggregates

The fine aggregate used was locally available river sand without any organic impurities and conforming to IS: 383 – 1970 [Methods of physical tests for hydraulic cement]. The fine aggregate was tested for its physical requirements such as gradation, fineness modulus, specific gravity and bulk density in accordance with IS: 2386 – 1963 [Methods of test for aggregate for concrete] and is shown in Table 2. The sand was surface dried before use.

Coarse Aggregate

The coarse aggregate chosen for SCC was typically round in shape, well graded and smaller in maximum size than that used for conventional concrete. The size of coarse aggregate used in self compacting concrete was between 10mm to 16mm. The rounded and smaller aggregate particles provide better flowability and deformability of concrete and also prevent segregation. Graded aggregate is also important particularly to cast concrete in highly congested reinforcement or formwork having small dimensions. Crushed granite metal of sizes 16 mm to 10 mm graded obtained from the locally available quarries was used in the present investigation. These were tested as per IS 383-1970 [Methods of physical tests for hydraulic cement]. The physical properties like specific gravity, bulk density, flakiness index, and elongation index and fineness modulus are shown in Table 2

Table 2: Physical properties of Coarse and Fine aggregate

S. No	Property	Method	Fine Aggregate	Coarse Aggregate
1.	Specificgravity	Pycnometer IS:2386 Part 3-1986	2.41	2.63
2.	Bulk Density Loose Compacted	S:2386 Part 3-1986	1548 kg/m^3 1680 kg/m^3	1451kg/m^3 1602kg/m^3
3.	Bulking	IS:2386 Part 3-1986	6% w c	--
4.	FlakinessIndex	(IS:2386 Part 2-1963)	--	8.08%
5.	ElongationIndex	(IS:2386 Part 2-1963)	--	0%
6.	FinenessModulus	Sieve Analysis (IS:2386Part 2-1963)	3.62	6.04

Water

Water used for mixing and curing was potable water, which was free from any amounts of oils, acids, alkalis, sugar, salts and organic materials or other substances that may be deleterious to concrete or steel confirming to IS : 3025 – 1964 part22, part 23 and IS : 456 – 2000 [Code of practice for plain and reinforced concrete]. The pH value should not be less than 6. The solids present were within the permissible limits as per clause 5.4 of IS: 456 – 2000.

Fly Ash

Fly ash is one of the most extensively used supplementary cementitious materials in the construction field resembling Portland cement. It is an inorganic, noncombustible, finely divided residue collected or precipitated from the exhaust gases of any industrial furnace. Most of the fly ash particles are solid spheres and some particles, called cenospheres, are hollow and some are the plerospheres, which are spheres containing smaller spheres inside. The particle sizes in fly ash vary from less than 1 µm to more than 100 µm with the typical particle size measuring less than 20 µm. Their surface area is typically 300 to 500 m2/kg, although some fly ashes can have surface areas as low as

200 m2/kg and as high as 700 m2/kg. Flyash is primarily silicate glass containing silica, alumina, iron, and calcium. The relative density or specific gravity of flyash generally ranges between 1.9 and 2.8 and the color is generally grey.

Flyash used in this investigation was procured from Kakatiya Thermal Power Project, Andhra Pradesh, India. It confirms with grade I of IS: 3812 – 1981 [Specifications for flyash for use as pozzolana and admixture]. It was tested in accordance with IS: 1727 –1967 [Methods of test for pozzolana materials]. A typical oxide composition of Indian fly ash is shown in Table 3. The chemical composition and physical characteristics of flyash used in the present investigation were given in Tables 4 and Table 5.

Table 3: Typical Oxide Composition of Indian fly ash

S No	Characteristics	Percentage
1.	Silica, SiO_2	49-67
2.	Alumina Al_2O_3	16-28
3.	Iron oxide Fe_2O_3	4-10
4.	Lime Ca O	0.7-3.6
5.	Magnesia Mg O	0.3-2.6
6.	Sulphur Trioxide SO_3	0.1-2.1
7.	Loss on Ignition	0.4-1.9
8.	Surface area m^2/kg	230-600

Table 4: Chemical requirements of fly ash

S No.	Characteristics	Requirements (% by weight)	Fly Ash used (% by weight)
1.	Silicon dioxide (SiO_2) plus aluminium oxide(Al_2O_3) plus iron oxide (Fe_2O_3)	70 (minimum)	94.46
2.	Silicon dioxide(SiO_2)	35 (minimum)	62.94
3.	Magnesium Oxide(MgO)	5 (max.)	0.60
4.	Total sulphur assulphur trioxide(SO_3)	2.75 (max.)	0.23
5.	Available alkalies as sodium oxide (Na_2O)	1.5 (max.)	0.05
6.	Loss on ignition	12 (max.)	0.30
7.	Chlorides		0.009

Table 5*:* Physical requirements of fly ash

S No	Characteristics	Requirements for grade of fly ash (IS:3812-1981)		ExperimentalResults
		Grade – I	Grade – II	
1.	Fineness by Blain's apparatus in m^2/kg	320	250	335
2.	Lime reactivity (MPa)	4.0	3.0	9.8
3.	Compressive strength at 28days as percentage of strength of corresponding plain cement mortar cubes	Not less than80%		86%
4.	Soundness by Autoclaveexpansion			Nil

<u>MIX PROPORTIONING</u>

The mix proportioning was done based on the Nan Su approach [2001]. The mix proportion is given in Table 6, for different aggregate sizes.

Table 6: Mix Proportion and Quantities of M30 grade of SCC

Size of Graded Aggregate (mm)	Mix Proportion	w/b	Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	S.P	VMA
20	1:0.75:1.5	0.455	210	300	944	791	9.12	1.75
12.5	1:0.425:1.250:1.181 :0.024	0.257	680	289.28	850.30	803.17	16.82	1.75
10	1:0.450:1.250:1.170: 0.023	0.269	680	305.50	850.30	795.65	15.85	1.75

Many different test methods have been developed in an attempt to characterize the properties of SCC. So far, no single method or combination of methods has achieved universal approval and most of them have their adherents. Similarly, no single method has been found which characterizes all the relevant workability aspects. Each mix design should be tested by more than one test method for different workability parameters. The requisite test methods are described in Table 7

Table 7: List of test methods for workability properties of SCC

S.NO	Method	Property
1	Slump flow test	Filling ability
2	T_{50}cm Slump flow	Filling ability
3	V-funnel test	Filling ability
4	V-Funnel at T_5 minutes	Segregation resistance
5	L-Box test	Passing ability
6	U – Box test	Passing ability
7	Fill box apparatus test	Passing ability
8	J-Ring	Passing ability
9	Orimet test	Filling ability
10	GTM screen stability test	Segregation resistance

Workability criteria for the fresh SCC

Filling ability, passing ability and segregation resistance are the requirements for judging the workability criteria of fresh SCC. These requirements are to be fulfilled at the time of placing of concrete. Typical acceptance criteria for Self-compacting Concrete with a maximum aggregate size up to 20 mm are shown in Table 8

Table 8: Acceptance criteria for Self-compacting Concrete

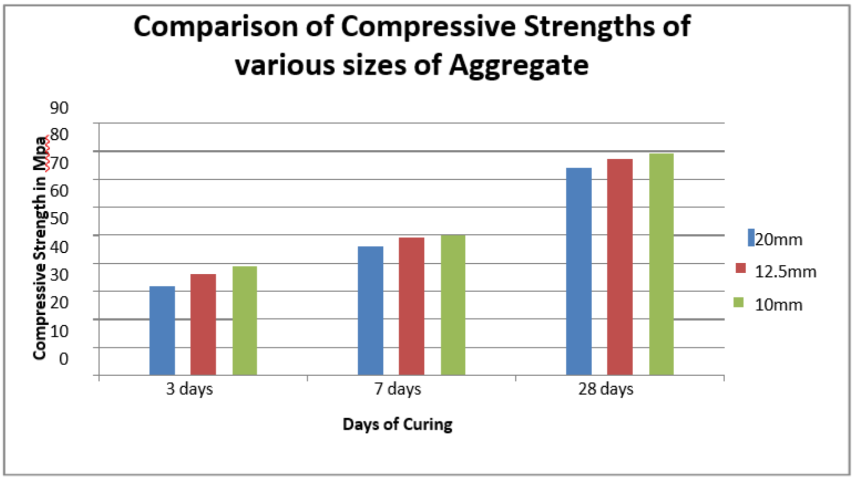
S No	Method	Unit	Typical range of values	
			Minimum	Maximum
1.	Slump flow test	mm	650	800
2.	T_{50} cm Slump flow	sec	2	5
3.	J – Ring	mm	0	10
4.	V – Funnel	sec	6	12

III. OBESERVATIONS AND TEST RESULTS

The parameters involved in the study are the size of aggregate (10, 12.5, 20 mm), age of curing (3, 7 and 28 days), grade of concrete (M30) and type of concrete (SCC)

As described earlier, Nan Su method of mix design [2001] was adopted to design the SCC mix for M30 grade of concrete. As understood, Nan Su method is based on the basic principle that the paste of binders are filled in the voids of aggregates ensuring that the concrete obtained has flowability, self-compacting ability and other desired SCC properties. The packing factors assumed on the basis of better compactability and strength, from a number of trials is 1.12 for M30 grade of concrete. From Nan Su method of mix design for SCC, the density, compactability and strength are dependent on how effectively the aggregates are packed. Hence, the size of aggregate, shape and texture of aggregate also plays a deciding factor in the values of fresh and hardened properties.

Figure 2 show comparison of compressive strength of various sizes of aggregate



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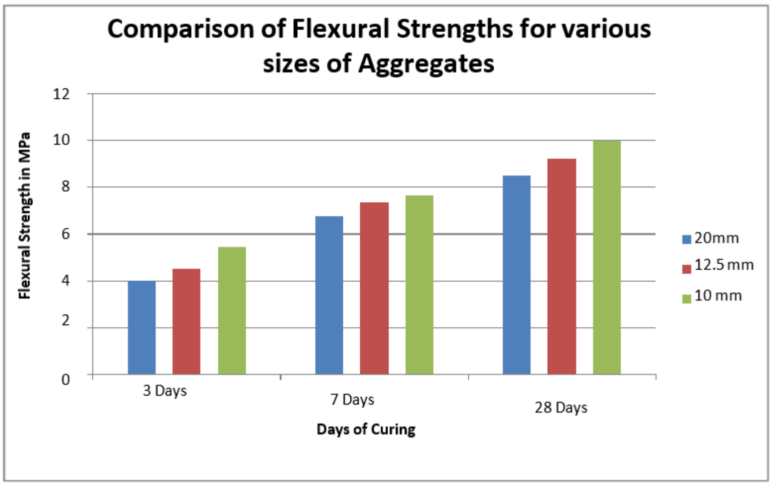

Figure 3: Flexural Strength with various sizes of Aggregate

IV. CONCLUSION

From the results of the studies on mechanical properties for M30 grade of SCC mix, it is clear that the effective size of aggregate was 10 mm.

From the above results and discussion on strength aspect of SCC, it can be broadly concluded that the Self Compacting Concrete is better from the performance point of view.

Based on the systematic and detailed experimental study conducted on SCC mixes with an aim to develop performance mixes, the following are the conclusions arrived.

The mixes designed using the lower size of aggregate yielded better fresh properties than higher size of aggregates.

As the strength of concrete increases, the effective size of aggregate has decreased.

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