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An Overview of the Properties of Self Compacting Concrete

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ABSTRACT: *This Paper reviews the recent studies which were carried out on Self Compacting Concrete (SCC) and compare it with Normal Concrete (NC). Almost all countries in the world are facing an acute decline in the availability of skilled labor in the construction industry, and hence the need of Special Concretes becomes very essential in this world where the use of concrete is just next to the water. The word "Special Concrete" refers to the concrete which meets the special performance and requirements which may not be possible by using conventional materials and normal methods of concreting. Self Compacting Concrete is one of the type of a special concrete which flows and consolidates under its own weight thereby eliminates the problems of placing concrete in difficult conditions and also reduces the time in placing large sections and at the same time giving high strength and better durability characteristics as compared to the Normal Concrete. This paper discusses the various aspects of SCC including the materials and mix design, different test methods such as V-funnel test, L- Box test etc., and also its performance characteristics and properties in the fresh and hardened state.*

Keywords– *Durability, SCC, Special Concrete, Superplasticizers, Viscosity.*

I. INTRODUCTION

The demand of Self Compacting Concrete (SCC) is growing rapidly due to the shortage of skilled labors for which it was originally developed mainly due the work of Okamura [1], it is also proved to be more economical, durable and termed as high performance concrete [2]. The advantages of SCC make this concrete more desirable all over the world which includes faster construction, reduces manpower, better finishes, easier placement, better durability, thinner concrete sections, lesser noise levels, no vibration, safer working environment [3]. The Concept of SCC originates from Japan in 1980s and the early developed Super Plasticizers were the main reason which made it possible to flow and self consolidate. The use of SCC is rising steadily over the years because of their advantages and many scientists and organizations carried out research on properties of SCC [4].

The quality of concrete construction is of utmost importance in order to have a durable concrete structure and one of the reasons to make a durable structure is proper compaction which requires skilled labors but due to shortage of skilled labors full compaction cannot be done which is shown in Fig 1. The solution to this is the use of self compacting concrete which compacts in every corner of formwork.

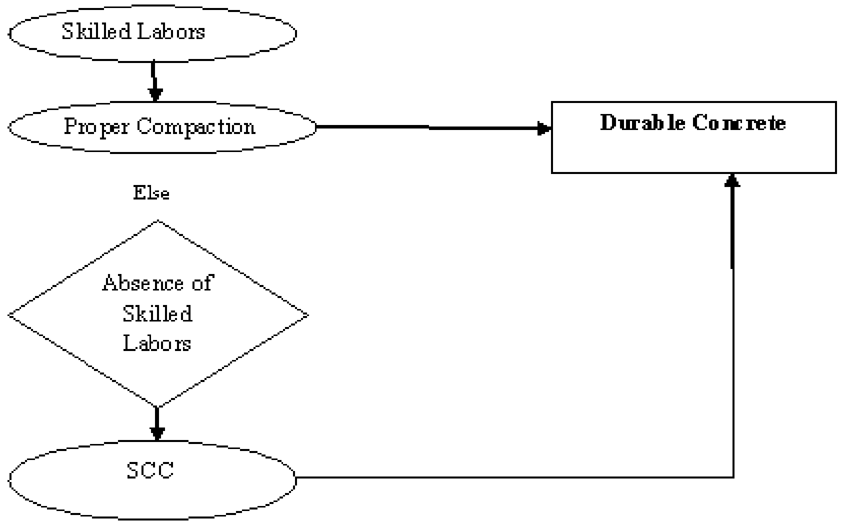

Figure -1 Necessity of SCC

In order to make this paper more reader friendly, it is divided into 4 parts namely materials and mix proportion, test methods for self-compatibility, properties in the fresh state and hardened state.

II. MATERIALS AND MIX PROPORTION

The materials generally required for producing self compacting concrete differs from the ordinary normal concrete as SCC uses **more powder content and less coarse aggregate in addition to high range water reducers (HRWR, superplasticisers) in a larger quantity and also frequently a viscosity modifying agent (VMA) in small doses.**

The factors which dominates the selection of materials are-

i. **Amount of aggregates used which are deviating from ideal shapes and sizes.**
ii. **Type of superplastizer used.**
iii. **Type of VMA.**
iv. **Compatibility between cement, superplastizer, and VMA.**

Aggregates

The shape and gradation of aggregates play an important role in producing a SCC. Much research has been conducted in this area to produce SCC by using locally available aggregates. Rounded aggregates are much preferred as they play an important role to achieve workability with lower cement content as compared to angular aggregates, [5, 6, 7]. However, it is possible to produce a flowable concrete by using angular aggregates by methods as suggested by **O'Flannery [8], and is tabulated in Table 1.**

Table 1- Use of Shape Characterization of Aggregate

	Conventional method	**Suggested method**
Aggregate shape	• **Rounded versus crushed (subjective assessment)** • **Flakiness index** • **Elongation index**	**•Cubicity, sphericity, and roundness indices (based on Flannery)** **- Cubicity (Cubicity index $I_c = 100XYZ/X^3$, where X, Y, and Z are the dimensions of the aggregate) to indicate the likely degree of potential compaction; values of index between 60 and 10 are cubic, between 30 and 60 indicate flakiness.** **- Sphericity index to describe the polyhedral shape of the particle**

		- Roundness index to describe the degree of angularity;
Adjustments in mixture proportioning	• **Adjustment in water content by type of aggregate – rounded or crushed** • **No recommendation for flaky aggregate**	**• Use index value for adjustment of mixture**

Poor gradation of aggregates is also one of the causes which may affect the flowability of SCC and using fillers, both inert and reactive may solve this problem [9, 10]. Because of unavailability of sand in present days due to the environmental impact **of mining river sand in India, alternative to fine aggregates or artificial sand is being used much as a filler to produce SCC, but not much research has been carried out on the effects of artificial sand on SCC till date. D. W. S. Ho [11] in his paper indicated the various advantages of Quarry dust instead of limestone to use as filler.**

Superplasticizers-

High range water reducing admixture plays an important role in the desirable flow at low water contents. Many researches [12, 13, 14] have been conducted in order to know the role of different types of Superplasticizers to achieve Self Compacting Concrete. These researches indicate that those Superplasticizers based on "steric hindrance" require a lower dosage than with those which based on "electrostatic repulsion". Thus in India, the sulfonated condensates of naphthalene (SNF) formaldehyde [15] is much preferable because of its low cost as compared to others.

Viscosity modifying agents (VMA)

VMA helps in reducing bleeding and thereby improves the stability of the concrete mixture. An effective VMA can also reduce the powder requirement, yet maintaining the required stability. And also, SCC almost always incorporates mineral admixture, to improve the deformability and stability of concrete. As it is a well known fact that the VMA's are in use since a long time (Ex- for underwater concreting) [16], they contain polysaccharides as active ingredient which controls the viscosity [17].

The compatibility between the cement and superplasticizers is an important issue to be considered as the gypsum present in the concrete having low water content and superplasticizers dosage may precipitate out resulting in loss of slump [18].

III. MIXTURE PROPORTIONING METHODS

The mix design of SCC should be done in such a way that it should have resistance to segregation, pass through and around the reinforcement without blockage. Fig. 2 shows the principles of producing SCC.

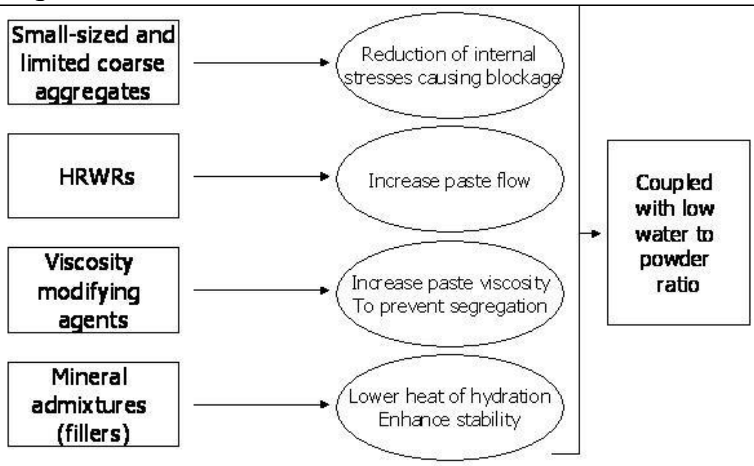

Fig 2- Principles of Producing SCC

The water content of SCC was very high in the past because of more cementitious content, but with the help of VMA, it is now possible to reduce the water content as same that of normal concrete yet giving a high slump. The various ways to produce SCC can be broadly classified into 4 categories, namely **(i) Empirical methods (iii) Particle packing models, and (iv) Statistical methods.**

Empirical methods

Okamura and Ozawa [19] have recommended a method in which 50 % of the solid volume is taken up by coarse aggregate (CA), while 40 % of the mortar volume is a fine aggregate (FA). Flow tests on mortar is then used to know the water to powder ratio and then adjustments are done with coarse and fine aggregates contents. Many researchers now use this method as a start up in their investigations.

Edamatsu et al [20] have modified this method in which the ratio of CA is kept at 0.5 but the content of FA is fixed using V- funnel test and the dosages of water to powder ratio and superplasticizers is then determined by flow and funnel tests. EFNARC [21] recommends the same method as used by Okamura but instead of fixing the CA content to 0.5, a higher amount of CA for rounded aggregates is allowed (0.6) and the sand is varied between 0.4 to 0.5. The comparison of these methods is given in table 2.

Particle packing models- Many researchers have proposed particle packing methods to produce SCC [22, 23, 24, 25]. The particle packing method is based on the theory of ceramic industry where the void contents of dry granular mixture of ingredients (cement and fly ash) is reduced by properly choosing the sizes and gradation of concrete.

Table 2. Empirical mixture proportioning methods for SCC

Proposed by	Max CA volume ratio	Maximum proportion of sand in mortar, percent	Paste composition (w/p ratio)	Remarks
Okamura and Ozawa	0.5	40 (empirical)	Mortar flow and V-funnel tests	Originally developed using moderate heat or belite rich cement
Edamatsu et al.	0.5	Determined by V-funnel test using standardised coarse aggregate	Mortar flow and V-funnel tests	Enables determination of stress transferability of mortar
EFNARC	0.5 – 0.6	40 – 50 percent (empirical)	Mortar flow and V-funnel tests	Allows more freedom in coarse aggregate content

Discrete models- In this model, the bigger size aggregates acts as the base frame and the smaller size particles fills the voids. The left over voids are filled with the finer particle and the chain goes on in decreasing order.

Sedran and de Larrard [26] used this model to produce SCC by entirely eliminating VMA and used the results from rheology measurements on fresh SCC, filling ability (L-box test), and resistance to segregation. By using the softwares, the mix proportion of SCC were then found optimizing the mixtures with regard to the properties.

Statistical Methods- Statistical methods have many advantages which include carrying out minimum number of experiments**.** Khayat [27] proposed a proportion method to produce SCC using different parameters such as cement content, w/c ratio, Superplasticizers and VMA concentrations, and amount of coarse aggregate at five dissimilar levels and measured slump, viscosity, V-funnel time, and filling ability. This method gives the interrelationships among the ingredients for performance optimization.

The various methods for mix proportion to produce SCC are summarized in Table 3.

Table 3

Type of concrete	Empirical methods	Particle packing	Statistical design
Conventional	Applicable; design tables available	Applicable; validation required	Applicable; not widely used
SCC	May be applicable	Applicable; validation required	Applicable

IV. TEST METHODS FOR SCC

The SCC in its fresh state is characterized by its abilities to fill, pass and its stability and not so in case of conventional concrete and hence there are few special tests to measure the performance of ingredients. There are various tests available and are given in Table 4 with their limiting values and some of them are discussed below.

Slump Flow Test- The slump flow test is shown in Figure 3-a, which is generally used to measure the flowability of SCC. The test is performed in a similar way as that for conventional concrete but instead of measuring vertical slump distance, the mean spread of concrete horizontally is measured. **Measured characteristic:** Filling ability, viscosity, and stability.

J-Ring Test [28]- In the J-Ring (Figure 3-b) a ring of reinforcing bar is fitted around the base of a standard slump cone. The slump flow is then measured with and without J-, and the difference calculated. The Visual Blocking Index is used to rate the segregation of the mixture during the test. **Measured characteristic**: Passing ability.

L-Box Test- The L-Box test is shown in Figure 3-c. This test evaluates the passing ability of SCC in which the concrete is placed inside the testing apparatus and a grill accompanied with the testing apparatus simulates reinforcement and the height of concrete in vertically and the end of the horizontal portion of the apparatus are measured. The ratio of these two is then used to measure the passing ability. **Measured characteristic:** Passing ability.

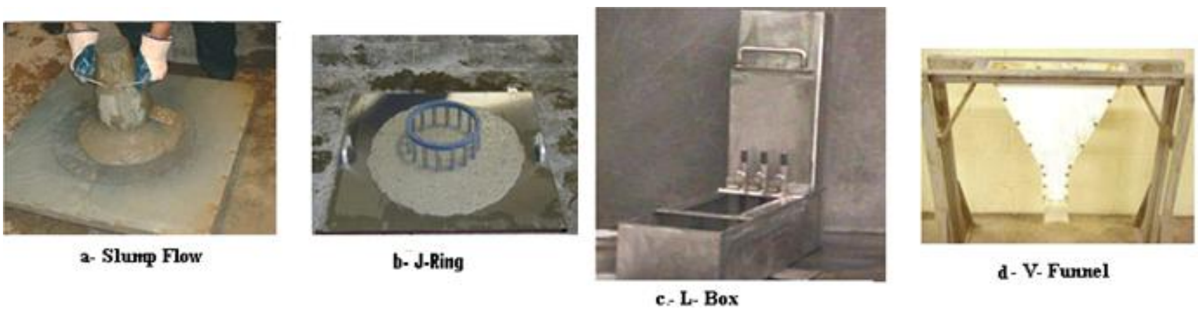

Figure 3- Various tests for SCC

V-Funnel Test- The V-Funnel test consists of a V-shaped apparatus as shown in Figure 3-d which consists of an opening at the bottom. The viscosity of the mixture is measured by the time taken to empty the funnel. Using the V-funnel test, the viscosity and the ability to parts through opening at bottom can be obtained. A number of factors along with viscosity, slump flow, size distribution and amount and shape of coarse aggregate affects the V-funnel flow time, [29]. Not much research has been done so far on the effects of shape of aggregates of SCC. **Measured characteristic:** Viscosity.

Table- 4- Testing methods and limiting test values for SCC

Property	Test method	Material	Recommended values
Flowability / Filling ability	Slump flow	Concrete	650 – 800 mm Average flow diameter
	V – funnel	Concrete	6 – 12 sec Time for emptying of funnel
Passing ability	L – box	Concrete	0.8 – 1.0 Ratio of heights at the beginning and end of flow
	J - ring	Concrete	0 – 10 mm Difference in heights at beginning and end of flow

V. HARDENED CONCRETE PROPERTIES OF SCC

The higher flowability and a higher proportion of fine materials distinguishes the SCC from Conventional concrete. Apart from this, Table 5 gives the properties of SCC based on the results of various studies.

Table 5: Differences in performance of SCC and normally-vibrated concrete

Property of SCC	Expectation	Reality
Variation in strength	Can take place	No difference (between SCC and compacted concrete)
Creep and shrinkage	Higher	No significant difference
Early age shrinkage and cracking	Higher	Higher
Strength and elastic modulus	No difference for same grade of concrete	No difference
Durability	Better	Better

Uniformity- Various researches have been conducted so far and many have reported that the performance of SCC is not so different from a fully compacted conventional concrete. It was also observed that the in-situ strengths from the cores of walls and columns were similar for the SCC and conventional mixes [29]. Zhu et al. [30] studied further on this study by taking columns and beams on the uniformity.

Creep and shrinkage of SCC- The hydrated cement paste generally governs the creep and shrinkage of concrete and because of more paste content (flyash), SCC have higher tendency to creep. However in a study B. Persson [31], the strength, elastic modulus, creep and shrinkage of SCC and normal concrete does not differ much except that the creep was more at the initial ages of SCC.

Keeping the cement content same as that of conventional concrete may reduce the creep and shrinkage. It was also observed that SCC cracks more at time between (2-8 hours), [32]. Turcry et al. [33] reported that the plastic shrinkage of SCC was two times higher than the normal concrete at the same evaporation rate. Thus with low powder content, these cracks can be reduced.

Compressive and Flexural Strengths- Compressive strength was studied by Rols et al. [34]; Sari et al.[35]; Su,N., et al. [36]; Corinaldesi,V., et al. [37]; Nehdi & Ladanchuk,[38]; Sonebi,M.,[39, 40]; Persson, B., [41]; Kumar, P., et al. [42]. Compressive strength was reported at 1,7,28 and 90 days of cylinders 110 mm in dia and

220 mm high with rate of loading as 5 KN/s by Rols et al [43]. Persson, B. [44] compared the mechanical properties of SCC and the corresponding properties of conventional concrete and carried out the study on four different stress to strength levels on 100 mm cubes at 2, 7, 28, 90 and 365 days. Corinaldesi,V. et al. [37] studied compressive and flexural strength of cubic specimens 100 mm in size and prismatic specimens (100*100*500mm). Fig 4 gives the compressive strength and flexural strength as function of curing time. Nehdi, et al. [38] reported that the binary 50% - OPC 50% fly ash mixture had the lowest early age strength due to the slower reactivity of class F fly ash. Studies have indicated that some of this strength decrease may also be due to increase in the air content of mixture by 0.5 % when VMA was added.

Durability of hardened SCC

Many important structures such as bridges, dams are built using SCC and showing promising results [45]. The durability of concrete can be best understood by its permeability characteristics. Zhu et al. [46] found that SCC has lower water sorptivity and oxygen permeability compared to normal concrete. In one of the research [47], the core samples were taken from bridges and retaining walls and tested for chloride penetration and it was observed that the specimens had a higher resistance to chloride penetration as compared to conventional concrete at the same water to cement ratio. Persson B. [48] did study of frost durability of SCC and found that with the same air content the internal frost resistance of SCC was much superior to the reference concrete, whereas the salt scaling was similar in the both the concretes.

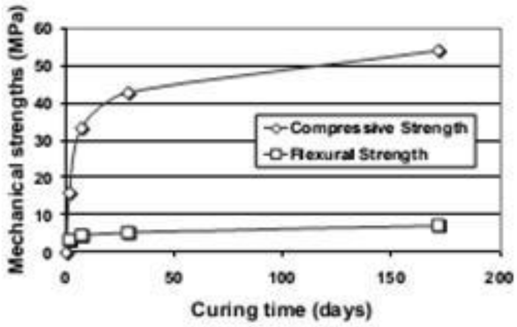

Figure: 4 Compressive and Flexural Strengths of the concrete as a function of curing time from Corinaldesi et al. 2004

VI.CONCLUSION

Particularly in India, the use of Self-compacting concrete for routine construction is not much because of the lack of awareness while in countries like Canada apart from Japan, SCC is used for the routine construction and with research data available, an awareness can be spread in order to utilize the various benefits of this material. It is not fully clear whether existing design codes for structural concrete can be practical in case of self-compacting concrete. Use of viscosity modifying agents along with high-range water reducing agent are very essential for flowability and segregation control. A better understanding of the rheology of SCC has made it easier to know the functions of fines, superplasticizers, and VMA in SCC, and the compatibility between these and gives the designers a clear understanding of the mechanical properties including stress strain characteristics of SCC in its hardened state. No standard codes are available for the mix design of self compacting concrete apart from few methods developed by the researchers and many institutions, RMC, companies are using their own methods with one or other limitations. Thus some generalized method can be developed taking into the consideration all the aspects.

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