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Self Compacting Concrete – A Boon To Construction Industry

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ABSTRACT

Self compacting concrete (SCC) consists one of the very latest developments in concrete technology. With its excellent deformability, high fluidity, and better durability potential, it marks a milestone in the construction industry. SCC is a highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any consolidation and without undergoing any significant separation. It also offers a rapid rate of concrete placement, with faster construction pace and ease of flow around congested reinforcement. The flowability and segregation resistance of SCC ensures a high level of homogeneity, minimal voids and uniform concrete strength providing the potential for a superior level of finish and thus durability of the structure. The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise and vibration. This advantages construction practice and performance with reduced health and environment hazards make SCC a highly acceptable one for both precast and cast in situ construction. This paper deals with the history of SCC development and its basic principle, different testing methods to test high-flowability, resistance against segregation, and passibility, benefits and limitations, usage and applications. It is not an all-encompassing document but is an introduction to the subject providing general information on various aspects.

KEYWORDS : Admixture, Deformability, Durability, Plasticizer, Segregation, Self Compacting Concrete.

INTRODUCTION

Self-consolidating concrete or self-compacting concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. It is a new class of high-performance concrete that can spread readily and fill restricted sections as well as congested reinforcement structures without the need of mechanical consolidation and without undergoing any significant separation of material constituents. SCC was conceptualized in 1986 by Prof. Okamura at Ouchi University, Japan[1]. It is characterized by a low yield stress, high deformability, and moderate viscosity necessary to ensure uniform suspension of solid particles during transportation, placement (without external compaction), and thereafter until the concrete sets giving a far superior surface than conventional concrete. Workability requirements for successful casting of SCC include high deformability, passing ability, and proper resistance to segregation and this ability to flow and filling all spaces within the formwork, under its own weight referred deformability. It is an emerging class of concrete materials that offers great potential for improved ease of placement, increased rate of construction, and reduced cost through reduced time and labour. Though the concept of SCC was introduced in 1986 by Hajime Okamura, Prof. Ozwa of University of Tokyo developed the first Prototype in 1989 [2, 3].

DEVELOPMENT OF SCC WORLDWIDE

Its initial development was in Japan in the late 1980s and subsequently introduced in Europe through Sweden in mid to late1990s [4]. The following Table.1, gives the overall view.

Table.1, Worldwide development of SCC

S.No	Country	Developments
01.	Japan	SCC was first developed in Japan in 1988. One of the main drivers for the development of the technology was the reduction in the number of skilled site operatives that the Japanese construction industry was experiencing in the 1980s.
02.	England	First research work to be published from Europe was at an International Union of Testing and Research Laboratories of Materials and Structures Conference in London in 1996.
03.	Sweden	Sweden was at the forefront of the development of SCC outside Japan and it is estimated that SCC now accounts for approximately 7–10% of the Swedish ready-mix market, up from approximately 3% in 2000.
04.	France	French recommendations for the use of the material were established in July 2000 and are used as reference on construction sites.
05.	Germany	SCC requires technical approval before it can be used on site and at least six different universities and research establishments in Germany are conducting research.
06.	Belgium	A Belgian national contact group on SCC exists chaired by Professor De Schutter of the University of Ghent. They meet universities, contractors, suppliers and other interested parties meet several times a year to discuss the development.
07.	Spain	SCC production is just beginning in Spain, but the first structures have already been constructed in Malaga, Valencia and Madrid.
08.	Holland	The precast concrete industry in the Netherlands first became interested in SCC in 1998. Although the Belton project was formally completed in December 1999, intensive collaboration in SCC is still continuing.
09.	Switzerland	Research into SCC has been conducted at the Swiss Federal Institute of Technology (ETH) in Zurich and at the Swiss Federal Institute for Materials Testing and Research in Du¨ bendorf.
10.	Italy	In Italy the majority of SCC applications are in the precast market, although it has been used for in situ applications.

COMPOSITION AND MIX DESIGN

Proportioning of the mix is extremely important in developing an effective Self-Compacting Concrete. This involves either modifying the cement paste, or carefully tuning the aggregates or both [5]. The relatively high cost of material used in concrete continues to hinder its widespread use in various segments of the construction industry, including commercial construction. However the productivity economics take over in achieving favorable performance benefits and works out to be economical in pre-cast industry. The reduction in cement content and increase in packing density of materials finer than 80 µm, like fly ash etc. can reduce the water-cement ratio, and the high-range water reducer demand. The reduction in free water can reduce the concentration of viscosity-enhancing admixture necessary to ensure proper stability during casting and thereafter until the onset of hardening. It has been demonstrated that a total sand content of about 50% of total aggregate is favourable in designing for SCC. Its flowability is generally achieved by using polycarboxylate-based high-range water-reducing admixtures and optimized concrete ingredients while maintaining a low mixing water content in the concrete.

While mixing, SCC looks very different from conventional concrete. Traditionally, concrete with the fluidity of SCC has had a very high water-cement ratio, which would lower compressive strengths and compromise durability. Two important properties specific to SCC in its plastic state are its flowability and stability. A typical Mix design/adjustment procedure is shown below in figure1. The high flowability of SCC is generally attained by using high-range water-reducing admixtures and not by adding extra mixing water. The stability or resistance to segregation of the plastic concrete mixture is attained by increasing the total quantity of fines in the concrete and by using admixtures that modify the viscosity of the mixture and the increased fines contents can be achieved by increasing the content of cementititious materials or by incorporating mineral fines.

This will help the SCC in achieving with reduced cementitious materials content and reduced admixture dosage. While SCC mixtures have been successfully produced with 1 ½ inch (38 mm) aggregate, it is easier to design and control with smaller-sized aggregate. SCC mixtures typically have a higher paste volume, less coarse aggregate, and higher sand-to-coarse aggregate ratio than typical concrete mixtures. [6]

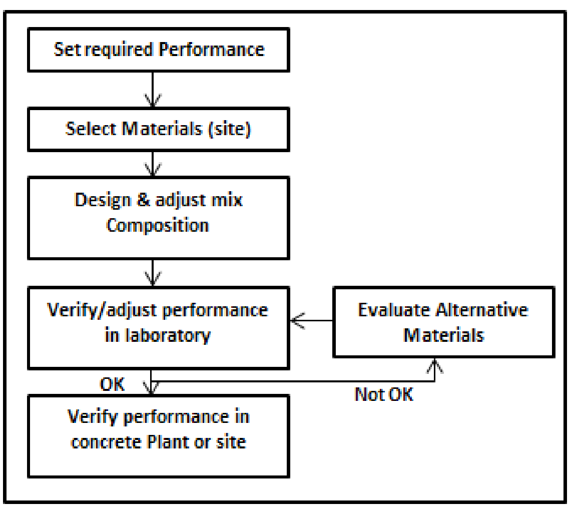

Fig 1.Typical Mix design /adjustment chart

DEVELOPMENT OF SCC IN INDIA

The use of self–compacting concrete in India was actually a matter of academic interest in the initial stages. This was the case owing to the higher initial cost compared to the traditional method of concreting. But, as many construction companies repeatedly found themselves in situations of time constraints and placement difficulties, the method of self-compacting concrete started flourishing in Indian sub-continent too.

In India, the development of concrete possessing self-compacting properties is still very much in its initial stages. Over the past couple of years, few attempts were made using European Guidelines for testing SCC in the laboratories and in the field. Ultra Tech Concrete, a division of Ultra Tech Cement Limited, and India's largest manufacturer of ready-mix concrete is the first commercial supplier of M80 Self-Compacting Concrete in India "Ultra Tech Free flow". There are many organization/academic institutions/cement companies in India who are working hard in the laboratory and field for the advancement and use of SCC in structures to minimize carbon emission and making cost effective construction product. Successful usage of high strength (M80) self-compacting concrete was reported for columns of Palais Royale, 320m tall residential building in Mumbai, India using a combination of cement, fly ash and silica fume or metakaolin. The Kesar Solitaire is a prestigious project being developed by Kesar Group, when completed would be a landmark on the Palm Beach Road in Navi Mumbai. The SCC mix was designed with "Corniche SF" brand Silica Fume to take care of the chloride ion permeability of the structure due to the saline water table.

Table.2, Calculation of the Water demand for 1m³ of Self Compacting Concrete mixture

Material	SCC Mixture (kg/m³)	Water Demand (% of mass)	Water Demand (kg/m³)
Cement: fly ash (1: 0.387 by mass)	380+147 = 527	27.5	145
Aggregate Size 0/2 mm	824	1.73	14.25
Aggregate Size 2/8 mm	412	0.93	3.84
Aggregate Size 8/16 mm	412	1.06	4.37
Water Demand	-	-	167.5
W/C ratio = 0.45	-	-	171.0
Difference	-	-	3.5

Table 3, Self-Compacting Concretes in early Eighties

S.No	Ingredient	Self Leveling and very Cohesive concrete placed under water	Self Compacting concrete for mass concrete foundations
01.	Ordinary Portland Cement	400 kg/m³	300 kg/m³
02.	Fly Ash	-	90 kg/m³
03.	Very fine sand (0.075 – 0.6 mm)	180 kg/m³	-
04.	Sand (0 – 5 mm)	990 kg/m³	670 kg/m³
05.	Gravel (5 – 15 mm)	630 kg/m³	305 kg/m³
06.	Gravel (10 – 20 mm)	-	710 kg/m³
07.	Water	190 kg/m³	187 kg/m³
08.	Plasticizer	7 kg/m³	4 kg/m³
09.	Water Cement ratio	0.47	0.62
10.	Slump	260 mm	220 mm

SCC was used by Nuclear Power Corporation of India Ltd at Tarapur, Kaiga and Rajasthan Atomic Power Project. Some pioneering efforts have been made in Delhi Metro Project. Debashis Das et al. [7] have carried out experimental investigation of SCC using Micro-silica and flyash from Thermal Power Plant, Dadari, Delhi. Vengala et al. [8] developed SCC using flyash from Thermal Power Station, Silchar, Karnataka. Naveen Kumar et al. developed SCC using blend of flyash and metakaolin [9]. Praveen Kumar et al. used stone crusher dust partially replacing aggregates to obtain SCC. In all the above investigations, European standards were followed for determining rheological properties of Self compacting concrete. Results of above mentioned investigations are reproduced in the following table.4.

Table 4, Comparison of Self Compacting Concrete Case studies in India

S No	Particulars	Delhi Metro Project	Tarapur Project	Kaiga Project	Debashis Das et. al.	Vengala et. al.	Naveen Kumar et. al.	Praveen Kumar et. al
01	Cement (kg/ m³)	330	300	225	291.2	431	450	250
02	Fly Ash (kg/ m³)	150	200	225	291.2	163.78	66	350
03	Kaolin (kg/ m³)	0	0	0	0	0	82	0
04	Sand (kg/m³)	917	976	1024	1062.2	849	789	935
05	Aggregate (kg/m³)	764	664	762	455.2	650	664	623
06	Water (kg/ m³)	163	175	165	186.3	241	225	160.9
07	Plasticizer	2.4 %	2.4 %	1.80 kg/ m³	10 kg/ m³	0.65 %	0.5 %	2.3 %
Rheological Properties								
08	Slump (mm)	680	686	700	670	635	720	630
09	V Funnel Test (sec)	8	14	8.3	14	3.5	6.3	-
10	L Box Test	0.91	0.95	0.92	-	0.85	10	6.2
11	U Box Test (mm)	-	10	9.6	10	12.2	0.9	10
Compressive Strength								
12	7 days Strength (MPa)	33	48.06	40	30	38	25.27	23.5
13	28 days Strength (MPa)	44	56.93	51.3	50.1	51.2	47.57	32.6

COMMON TESTS OF SCC

The common tests currently used, although not standardized for assessments of fresh SCC [10] are described here.

1. Slump Flow Test for Measuring Flowability: The basic equipment used is the same as for the conventional Slump test is shown below in fig.2. The test method differs from the conventional one in the way that the concrete sample placed into the mould has no reinforcement rod and when the slump cone is removed the sample collapses. The diameter of the spread of the sample is measured, i.e., a horizontal distance is measured as against the vertical slump measured in the conventional test. While measuring the diameter of the spread, the time that the sample takes to reach a diameter of 500 mm (T50) is also sometimes measured. The Slump Flow test can give an indication about the filling ability of SCC and an experienced operator can also detect an extreme susceptibility of the mix to segregation.

2. V-funnel Test: The V-funnel test was developed in Japan and used by Ozawa. The equipment consists of a V-shaped funnel, shown in below figure.3. The funnel is filled with concrete and the time taken by it to flow through the apparatus measured. This test gives account of the filling capacity (flowability). The inverted cone shape shows any possibility of the concrete to block is reflected in the result.

3. L-box Test: The L-box test method uses a test apparatus comprising a vertical section and a horizontal trough into which the concrete is allowed to flow on the release of a trap door from the vertical section passing through reinforcing bars placed at the intersection of the two areas of the apparatus, shown in below figure.4.The concrete ends of the apparatus H1 and H2 measure the height of the concrete at both ends. The L-box test can give an indication as to the filling ability and passing ability.

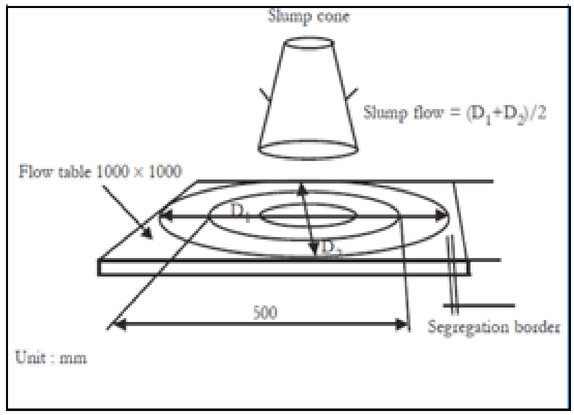

Figure.2, Slump Cone Test

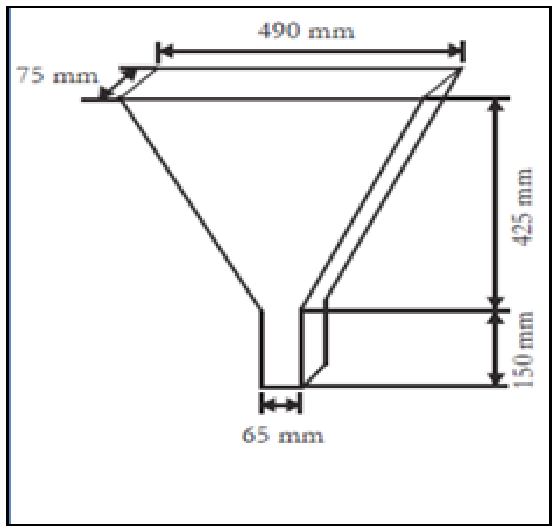

Figure.3, V Funnel Test

4. Blocking Ring (J-Ring) Test: The J-ring test is another type of method for the study of the blocking behaviour of self-consolidating concrete shown in figure.5. The apparatus consists of re-bars surrounding the Abram's cone in a slump-flow test, as in below figure. The spacing between the re-bars is generally kept three times of the maximum size of the coarse aggregate for normal placement of reinforcement consideration. The concrete flows between the re-bars after the cone is lifted and thus the blocking behavior/passing-ability of SCC can be assessed.

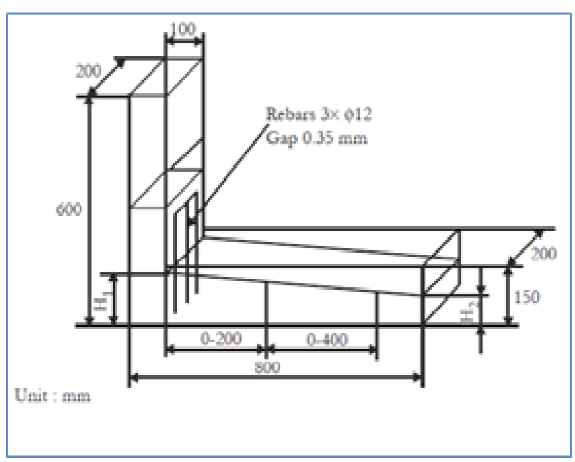

Figure.4, L Box Test

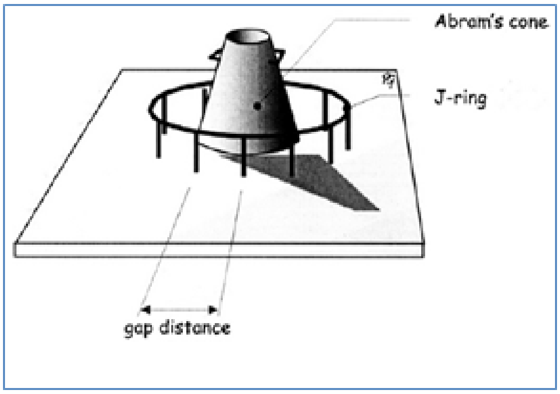

Figure.5, J Ring Test

CONCLUSION

For SCC more stringent requirements on the selection of materials and more precise measurement and monitoring of the constituent materials are required. An uncontrolled variation of even 1% moisture content in the fine aggregate could have a much bigger impact on the rheology of SCC. It also requires more trial batches at laboratory as well as at ready mixed concrete plants. Use of SCC can also help minimize hearing-related damages on the worksite that are induced by vibration of concrete, improve productivity in structural applications such as repair, and facilitate the filling of restricted sections. SCC is considered to be the most promising building material for the expected revolutionary changes on the job site as well as on the desk of designers. However, the basic principles of this material are substantially based on those of flowing, unsegregable, and super plasticized concretes developed in the mid of 1970's.In Practice it has been seen that by aging and hardening of concrete mixes, the module of elasticity like compressive and flexural strength increases. Normal concrete mixes show bigger module of elasticity around 9% to 17% more than of SCC [11]. Furthermore it has been proved experimentally that the values for engineering properties like compressive strength, Tensile strength, Static Modulus of elasticity, Creep, Shrinkage, Coefficient of Thermal expansion, bond strength, shear force capacity, fire resistance, durability show appreciably better ones in case of SCC than normal concrete[12].

The most important progress achievable in the future for this technology depends on the availability of More effective super plasticizers (based on acrylic polymers) with respect to the traditional ones (naphthalene or melamine based) in terms of lower slump loss. [13] Viscosity modifying admixtures (based on organic polymers) and ultra-fine amorphous colloidal silica. Considering the economy and the durability of conventional concrete structures, it is observed that the quality and the density of the concrete, as well as the compaction of the concrete are main parameters that cause deterioration and for this, SCC offers new possibilities and prospects.

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