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# Review on Behaviour of High Strength Self Compacting Concrete

MahendraKothari[a], Digvijay Singh Chouhan[a], Trilok Gupta[*], Ravi K Sharma[a]
[a]*Department of Civil Engineering, College of Technology and Engineering, MPUAT, Udaipur, India*
**Corresponding author: Trilok Gupta*

***Abstract:*** *Over the years, concrete structures designed on the basis of strength have been able to meet the criterion of safety however the compliance of durability criterion remained a distant dream. As a result, many concrete structures were out of service or they were rehabilitated at a huge cost. Most of these concrete structures were erected by producing and placing concrete at the site, which results in many workmanship problems e.g. honeycombing, segregation of aggregates, bleeding, sand streaking, and many other problems. Proper shuttering, mix design, proper placing and vibration can only be overcome many of these problems. Recently, these problems have been addressed and a viable solution has emerged in the form of Self-compacting concrete, SCC and High strength self-compacting concrete, HSSCC. In the last decade, use of SCC and HSSCC has provided remedies from many of these problems in Japan, Europe and North America. In this paper, the behaviour of HSSCC is critically reviewed. Properties of materials used to prepare HSSCC are discussed first, followed by the properties of HSSCC. This type of HSSCC has been used in many applications. It has been shown that the use of HSSCC offers economic, social and environmental benefits over traditional vibrated concrete constructions.*

***Keywords:*** *self-compacting concrete, high strength, compressive strength*

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## I. INTRODUCTION

Self-compacting concrete (SCC) is highly engineered concrete with much higher fluidity without segregation and is capable of filling every corner of formwork under its self-weight[1]. SCC eliminates the need for vibration either external or internal for the compaction of concrete without compromising its engineering properties. Self-compacting concrete is flowable and deformable without segregation, in order to maintain deformability along with flowability in a paste, a superplasticizer is considered indispensable in the concrete to maintain w/c ratio. An optimum combination of water-to-cementitious material ratio and superplasticizer for the achievement of self-compactibility can be derived for fixed aggregate content concrete through laboratory trial mixture proportioning [1].

In the world demand of high strength structures lead to have more emphasis on use of high strength material, in this context SCC also need to be updated hence there is need of high strength self compacting concrete satisfying he need of construction sector around the world. SCC is lacking behind in the terms of strength and durability, therefore to improve the performance of concrete in terms of strength and durability, High strength self-compacting concrete(HSSCC) is required. As per Indian Standard Code 456: 2000 with the amendment no. 4, May 2013, high strength concrete ranges from M65 to M100 [2]. The production of HSSCC can be done by adding some special ingredients and construction practices which helps in achieving more complex design. HSSCC has various advantages such as better quality assurance, mechanical appearance and durability. Alternative materials, such as fly ash, silica fume, mineral admixtures can be used to partially substitute the cement. HSSCC is the future of concrete which offer rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement

In this review paper, the behaviour of HSSCC is critically reviewed and properties of materials used to prepare HSSCC are discussed first, followed by the properties of HSSCC. Salient case studies of HSSCC havebeen also reviewed with concluding remarks at the end which will be helpful for the researchers and inventors working in this core.

## II. PROPERTIES OF MATERIALS USED IN HIGH STRENGTH SELF COMPACTING CONCRETE

Materials used to prepare High strength self-compacting concrete (HSSCC) are cement, coarse aggregate, fine aggregate, silica fume, metakaolin, fly ash, superplasticizer, and water.

**Silica fume:** Silica fume is also known as micro silica, condensed silica fume, volatized silica or silica dust [3]. The American Concrete Institute (ACI) defines silica fume as “very fine non-crystalline silica produced in electric arc furnace as a byproduct of the production of elemental silicon or alloys containing silicon”. It is used in HSSCC toreduce thermal cracking caused by the heat of cement hydration and improves the durability to attack sulphate and acidic water.

**Metakaolin:** Metakaolin is a high-quality pozzolanic material, which is blended with cement in order to improve the durability. Metakaolin is used in HSSCC as to removes chemically reactive calcium hydroxide from the hardened cement paste. It also reduces the porosity of hardened concrete. Metakaolin densified and reduces the thickness of the interfacial zone, thus improving the adhesion between the hardened cement paste and particulars of sand or aggregate [4].

**Fly Ash:** Fly ash is available in dry powder form is used in HSSCC. Fly ash used in HSSCC should satisfy the parameters given in Indian standard IS: 3812-1981 [3,5]. Purpose of fly ash in HSSCC is to minimize the water which indirectly increases the strength. Also, fly ash contains larger or less reactive particles than cement, significant hydration happen, which ultimately leads to higher strength.

**Superplasticizer:** Superplasticizer should conform Indian Standard IS: 9103-1999to prepare HSSCC [6]. Superplasticizers are used to obtain satisfactory workability of fresh concrete for all the mixtures. These are used with some chemical or mineral admixtures that provide the necessary viscosity [7].

## III. PROPERTIES OF HIGH STRENGTH SELF COMPACTING CONCRETE

The properties of high strength self-compacting concrete (HSSCC) in fresh and harden stages comprising of workability, compressive strength, split- tensile strength, flexural strength, creep-shrinkage, modulus of elasticity and durability properties as are discussed below:

### 3.1 Fresh concrete properties

The acceptable ranges of parameters and their suitability at laboratory and construction site have been shown in the Table 1.

**Table 1:** Acceptable range of parameters [8]

| Test | Range | Suitable for | |
|---|---|---|---|
| | | Laboratory | Site |
| Slump flow (final spread) | 600 mm | Yes | yes |
| Slump flow time (T-50) | < 12 s | Yes | yes |
| V-funnel time | 4-12 s | Yes | yes |
| V-funnel time after 5 min. wait | Initial value + 3 s | Yes | yes |
| J-Ring diameter change | < 50 mm | Yes | yes |
| L-Box (height ratio) | 0.80 | Yes | No |
| U-Box ( height difference) | <30 mm | Yes | No |

### 3.1.1 Segregation resistance

Rols, et al.[8] reported the segregation resistance testing method for rapid assessment of segregation resistance of SCC not only in the vertical direction, but also in the horizontal direction. The test results showed that the test method can reduce testing time and laboratory work. The proposed method could also distinguish between different coarse- total aggregate ratios, different water-binder ratios and different materials. The rate of bleeding was studied and Stress-strain relationship was recorded [8] and measured [12] drying shrinkage of prismatic specimens (100*100*500mm) at different curing times.

### 3.2 Hardened properties

### 3.2.1. Compressive Strength

Compressive strength test were conducted and observed by the various researchers [8-14]. Compressive strength test was reported at 1,7,28 and 90 days of cylinders 110 mm in dia and 220 mm high with a rate of loading as 5 KN/s [8,14] and compared the mechanical properties of SCC and the corresponding properties of normal 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.Studies have indicated that strength decrease may also be due to an increase in the air content of the mixture by 0.5 % when VMA was added. It wasreported the results on the uniformity of in situ properties of SCC mixes in practical structural columns and beams and compared the results with those of properly compacted conventional concrete.

**3.2.2. Permeability**

Different types of permeability tests were reported by researchers [12,15-18]. Carbonation, chloride permeability, carbonation depth by phenolphthalein test and chloride penetration depth was measured as a function of time of exposure to a 10 % sodium chloride aqueous solution after water saturation of concrete specimens [15].It was observed that high volume replacement SCC made with ternary and quaternary cement have dramatically lower chloride ion permeability compared to that of a reference SCC made with 100% OPC.

Bapat et al. [11] also conducted a rapid chloride penetration test on specimens of SCC and control mix of conventional concrete.Jooss, M .and Reinhardt, H.W. [17] carried out the tests on 11 types of concrete ranging from normal- strength to high strength concrete, to polymer-modified and self-compacting concrete-establishing permeability and diffusivity of concrete as a function of temperature between 20 and 80$^o$C. The results indicated that the permeability increases by 13 – 62 % when the temperature is raised from 20 to 50$^o$C and by an additional increase to 80$^o$C.Zhu, W. and Bartos, P.J.M. [18] reported the results regarding oxygen permeability. The results indicated that for the 40 MPa strength grade, SCC mixes had a significantly lower coefficient of permeability than the reference concrete mixes.

**3.2.3. Diffusivity**

Jooss M and Reinhardt [17] carried out diffusion tests following standardized procedures according to DIN 52615, using the dry cup method as well as the wet cup method. It was reported that diffusivity increases by 10-21% from 20 to 50$^o$C and by 8-21% from 50 to 80$^o$C. Zhu, W. and Bartos, P.J.M. [18]observed that the diffusivity was very much dependent on the type of additional powder used in concrete. Both the SCC and the reference mixes using PFA showed much lower values of chloride migration coefficient than the other mixes.

**3.2.4. Tribological behaviour of SCC**

A tribometer was developed to measure the friction on the metal surface. Paratibha Aggarwal et al. [11] performed the tests and observations was made which revealed a set of mechanisms that depend on the properties of the interface (roughness of the plate, the sliding velocity against the plate, the pressure or normal stress and the nature of the de-moulding agent at the concrete/wall interface).Paratibha Aggarwal et al. [11] obtained the estimation of the lateral pressure of SCC on formwork during the casting process, using Janssen's model used in the statics of ensiled granular material. Results obtained indicate that finer and better-graded limestone dust significantly increases the deformability of the paste.

Nehdi et al. [13] investigated potential synergistic effects in SCC incorporating different steel and synthetic polymer macro and microfibers in various hybrid (single, binary, and ternary) combinations. Results indicated that fibres can have a rheological and mechanical synergistic effect and that optimized fibre combinations can increase toughness and flexural strength better while maintaining adequate flow properties for fibre-reinforced SCC.

Paratibha Aggarwal et al. [11] investigated the confinement effect of glass fiber-reinforced polymer (GFRP) tubes on the strength and ductility of short SCC cylindrical columns subjected to uniaxial compression and transverse loading and reported that SCC filled GFRP tubes had a comparable behaviour to that of NC filled GFRP tubes under both uniaxial compression and transverse load.

**3.3 Durability properties**

**3.3.1 Sulphate Resistance**

Pratibha Agarwal et al. [11] carried out a laboratory study from 1999 to 2002 on Sulphate resistance of self-compacting concrete. Results of various studies indicated that the limestone particles are much more sensitive to sulphate attack than when the particles are mixed with cement and covered by the cement gel. SCC made with high-volume replacement binary, ternary and quaternary cement achieved very low sulphate expansion compared to that of a reference SCC made with 100 % OPC [15].

**3.3.2 Internal frost resistance/ Salt frost scaling**

Different factors affecting frost resistance were increased amount of filler, different air content, and dissimilar method of casting. Thus, the investigations were carried out for effects of normal and reversed order of mixing (filler last), an increased amount of filler, fineness of filler, limestone powder, increased air content, and large hydrostatic concrete pressure. Less salt frosting was observed of SCC with limestone powder having higher fineness. SCC exhibited better internal frost resistance than Normal concrete [11].

**3.3.3 Resistance to freezing and thawing cycles**

Resistance to freezing and thawing was studied and reported that resistance to freezing and thawing was moderate and can be improved by the superficial application of a hydrophobic agent, which reduces water ingress into concrete [12,16].

**3.3.4 Deicing Salt Surface Scaling Resistance.**

Nehdi et.al. [15] observed that HVFA-SCC had poor performance under deicing salt-surface scaling in the laboratory, high volume replacement ternary and quaternary SCC can be designed to achieve comparable deicing salt surface scaling resistance to that of a reference SCC mixture made with 100% OPC.

## IV. CASE STUDIES

Many case studies of High Strength Self Compacting Concrete (HSSCC)have been reported in the literature. Salient case studies have been reported in this review paper and are discussed below:

**(a) CASE STUDY 1: High Strength Self Compacting Concrete Using Nano- Silica [19]**

Effect of Nano silica in the properties of self-compacting concrete (SCC) was studied. Fresh and harden properties (i.e. Compressive strength, Split- tensile strength, Flexural strength) of SCC with partial replacement of cement by nano silica in three different percentage such as 0%, 2%, 4%, 6% were evaluated. After evaluating the mechanical properties for the various mix and it is compared with the best result, for that mix the durability test is conducted and tested. The concrete mixtures investigated in this study were prepared with Portland cement type II, potable water and contrast SP430 and nano silica. The specific gravity of nano silica is 1.03, and they are silica particles with a maximum size of 10 nm. In addition, nano silica is a water emulsion with 50 % of dry solid and PH of 10. The control mix which was excluded of nano-silica.

**Table 2:** Fresh concrete test results [19]

| S.NO. | Nano Silica (%) | Slump flow (650 mm to800mm) | V-funnel (6 -12 sec) | L-box test [(h2/h1) = 0.8 to 1] | U-Box =30mm(max) |
|---|---|---|---|---|---|
| 1. | 0 | 780 mm | 9 | 0.85 | 22.24 |
| 2. | 2 | 786 mm | 10 | 0.95 | 25.65 |
| 3. | 4 | 790mm | 11 | 0.98 | 28.50 |
| 4. | 6 | 791 mm | 11 | 1.0 | 29.65 |

The result shows that addition of nano-silica in SCC about 4% increase the compressive strength by 18.8% as compared with conventional concrete. nano silica which is having large surface area is to improve compressive, flexural and split tensile strength at early ages, improved hydration characteristics and reduced porosity and water absorption when compared with conventional cementitious materials. The result shows that the addition of nano silica about 4% in SCC increase in Flexural strength by 16.01% as compared with conventional concrete due to the higher surface area of silica, it helps to achieve more strength. The result shows that addition of nano silica about 4% in SCC, increases in Split tensile strength by 23% as compared with conventional concrete due to the higher surface area of silica which leads improved in hydration process, it helps to achieve more strength.

So it can be concluded based on the experimental approach the use of nano-silica in self-compacting concrete following results are obtained. Due to observed workability and high flowability of SCC, it can be used in highly congested reinforcement structure as compare to conventional concrete. Use of 2% nano-silica in SCC, it increase in compressive strength, flexural strength, Split tensile strength about 11.93%,10.51%,13.09% respectively. Use of 4% nano-silica in SCC, it increase in compressive strength, flexural strength, Split tensile strength about 18.88%,16.01%,23% respectively. But the use of 6% of nano-silica in SCC, it decrease in compressive strength, flexural strength, Split tensile strength 0.4%,1.29%,14.4% compared with 4% addition of nano-silica in SCC respectively. Nano silica can also pave the path to reduce the cement content in concrete than the conventional mixes while maintaining same strength characteristics, which will lead into the production of "greener" concrete.

**(b) CASE STUDY 2: High Strength Self Compacting Concrete with Mineral and Chemical Admixture [1]**

Self-compacting concrete (SCC) can flow and consolidate under its own weight and de-aerated almost completely while flowing in the formwork. The use fine materials such as silica fume and Viscosity Modified Agent (VMA) can ensure the required properties of SCC that involved in this work. The high strength SCC obtained by using 53 grade OPC, silica fume and Superplasticizer GLENIUM B233. Mix proportion of the constituents was arranged by many trials to obtain compressive strength above 60 MPa. Mix proportions were checked for workability tests. This work was carried out as per the European guidelines EFNARC-2005.

Trials Mix Proportions – VMA: Mix design procedure was followed from the EFNARC (May 2005) guidelines. Recommended range for W/P ratio by volume is 0.85 to 1.1 and for coarse aggregate it is 50 to 60% in net volume of concrete. Variation of compressive strength with and without VMA has been shown in fig.1 and fig.2 respectively.

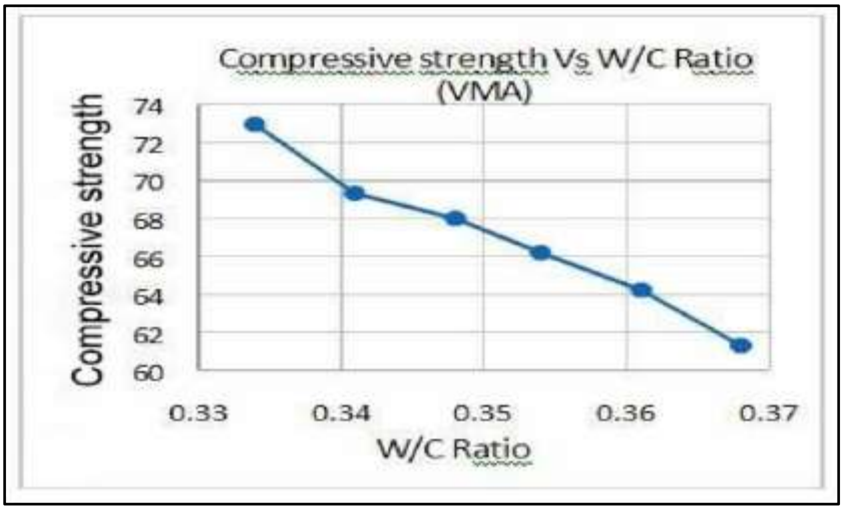


**Fig. 1.** Variation of compressive strength with w/c Ratio and VMA addition

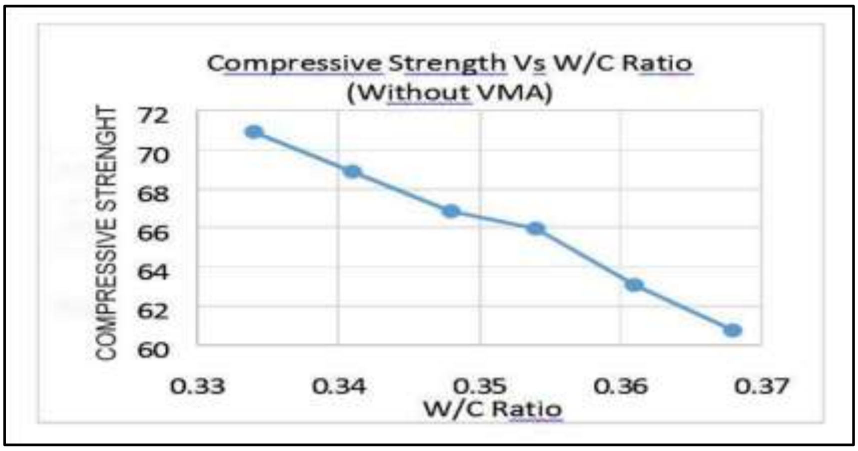


**Fig.2.**Variation of compressive Strength with w/c ratio without VMA addition

So it can be concluded with test results on fresh concrete are within limit, and follows EFNARC guidelines. Reduction of W/P ratio increases compressive strength. Optimum dosage of chemical admixture is 1.5-2%. Dosage of SP below 1.5% affects workability, over dosage affects setting time. Dosages of plasticizers require maintaining the self-compactibility of concrete, increased linearly by weight of cementations materials. Attention need at selecting water content for SCC without adding VMA, since rheological behaviour is more sensitive for water. Test results on fresh concrete with replacement of silica fume as 15-17.5% are within the limits of SCC. Compressive strength was obtained from 60.75 MPa to 70.92MPa for W/C ratio 0.368 to 0.334.

**(c) CASE STUDY 3: Durability Properties of High Strength Self Compacting Concrete (HSSCC) [20]**

In this case study, effect of $H_2SO_4$, $Na_2SO_4$ and HCL on High Strength Self Compacting Concrete. This study throws light on durability of high strength self-compacting concrete. It is believed that it is very much appropriate to discuss the strength and durability relationship, impact of water/cement ratio, permeability on durability of concrete. Variation of compressive strength at different grade has been shown in table 3.

**Table 3:** Compressive strength at 28 days with&without chemical immersion

| Grade | Compressive strength without chemical immersion | Chemical used(5%) | Decrease in Compressive strength after 28 day chemical immersion | Percentage decrease in compressive strength after 28 days |
|---|---|---|---|---|
| M80 | 82 $N/mm^2$ | HCL | 68.62 $N/mm^2$ | 16.31 |
| M80 | 82 $N/mm^2$ | $H_2SO_4$ | 43.40 $N/mm^3$ | 47.07 |
| M80 | 82 $N/mm^2$ | $Na_2SO_4$ | 65.71 $N/mm^4$ | 19.86 |

From the result of acid attack test on concrete specimen it can be concluded from test results obtained that Percentage decrease in weights of the specimens without and with immersion in HCL, $H_2SO_4$and $Na_2SO_4$solutions of 5 % concentration at 28 days was found to be 11.26%, 14.62% and 10.32 % respectively.

From these results it has been identified that the intensity of attack by $H_2SO_4$ is comparatively more than the attack of HCL and $Na_2SO_4$ on the specimens. The percentage decrease in compressive strength of the specimens without and with immersion in HCl, $H_2SO_4$and $Na_2SO_4$solution of 5 % concentration after 28 days was found to be 16.31, 47.07 and 19.86 % respectively. It is noticed that the intensity of attack by $H_2SO_4$ is comparatively more than the attack of HCL and $Na_2SO_4$ on the specimens, the reduction of strength due to the effect of $H_2SO_4$ on the concrete.

## V. CONCLUDING REMARKS

From the various available literature and case studies it has been found that high strength self compacting concrete provide more economical environment and social benefit over traditional vibrated concrete. It has provided solution to many environmental issues like, noise reduction in the place of manufacturing as well as at the place of application (site). It also prevents personal injuries from noise and manual handling. It reduces the consumption of electricity also.

Precaution has to be made in selection, more precise measurement, and monitoring of the materials used in HSSCC. Also more numbers of trials has to be done for HSSCC. From the above report it can be summarized as:

(1) The use of Nano-Silica as partial replacement of cement gives optimum result for compressive strength, flexural strength, and split tensile test.
(2) Silica fume in partial replacement with cement gives best result for compressive strength, and flexural strength.
(3) The effect of $H_2SO_4$ is more with compared to HCL and $Na_2SO_4$in reduction of weight and compressive strength of concrete.
(4) Better quality assurance, mechanical appearance and durability performance can also be achieved when HSSCC is used.

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