Mechanical and Durability Properties of Self Compacting Concrete containing Fly Ash and Steel Fibers

Thesis submitted in partial fulfillment of the requirements for the award of degree of

Master of Engineering
in
Structural Engineering

Submitted By
Gurwinder Kaur
Roll No: 821122013

Under the supervision of:
Dr. Rafat Siddique
Senior Professor

CIVIL ENGINEERING DEPARTMENT
THAPAR UNIVERSITY
PATIALA – 147004

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DECLARATION

I, Gurwinder Kaur, hereby declare that this thesis report entitled **"Mechanical and Durability Properties of Self Compacting Concrete containing Fly Ash and Steel Fibers"** submitted in the partial fulfilment of the requirements for the award of degree of Master of Engineering in Structural Engineering, in the Civil Engineering Department, Thapar University, Patiala, is wholly my own work. This matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Gurwinder Kaur

821122013

Date: 28/12/2014

Place: Patiala

CERTIFICATE

This is to certify that above statement made by the student concerned is correct and true to the best of my knowledge & belief.

Supervisor:

Dr. Rafat Siddique

Senior Professor

Civil Engineering Department

Thapar University, Patiala

Countersigned by:

Dr. Naveen Kawatra
Professor and Head (CED)
Thapar University, Patiala

Dr. S.S. Bhatia
Dean of Academic Affairs
Thapar University, Patiala

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(Gurwinder Kaur)

(821122013)

ABSTRACT

Self compacting concrete (SCC) is relatively a recent development in the construction world. SCC is defined basically by two properties: Deformability and segregation resistance. It flows under its own weight while remaining homogeneous in composition. This research is aimed at examining the feasibility of using steel fibers and fly ash as supplementary cementitious material. In this research, the main variables are the proportion of steel fibers by volume (0%, 0.5%, 1.0%, and 1.5%). Parameters kept constant are the amount of cement, fly ash, fine aggregates, coarse aggregates, water, SP content, w/b ratio.

The primary aim of this study is to explore the feasibility of using steel fibers in SCC by examining its fresh properties, mechanical properties (compressive strength, splitting tensile strength and flexural tensile strength) and durability properties (porosity, rapid chloride permeability and ultra sonic pulse velocity).

The test results revealed that the fresh properties were significantly influenced by steel fiber content. All the results were in range as per code specified. Mix SCC4 showed minimum workability. The increase of compressive strength of about 12% was observed from control mix (SCC1) to SCC3.The increase of about 44% tensile strength at 7 days, 39% tensile strength at 28 days was observed with increase of steel fiber content from control mix (SCC1) to SCC4. The increase of flexural tensile strength of about 24% at 7 days, 33% at 28 days was observed with increase of steel fiber content from control mix (SCC1) to SCC4. Maximum splitting and flexural tensile strength was also obtained by the mix SCC4. Greatest increase in mechanical properties was observed for the mix containing 1.5% steel fibers i.e. SCC4. The inclusion of fly ash as replacement of cement and steel fibers improved strength properties for all the SCC mixes. The inclusion of 10% fly ash as replacement of cement and steel fibers (0.5%, 1.0% and 1.5%) does not affect the durability properties negatively as they showed low chloride penetration range for all mixes and maximum increase in porosity is 6% for SCC4 mix. The decrease in ultra sonic pulse velocity was about 17% from control mix (SCC1) to SCC4.

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%	Percentage
min	Minutes
mm	Millimetre
cm	Centimetre
m	Meter
L	Litre
sec	Second
g/cm^2	Grams per centimetre square
cm^2/g	Centimetre square per gram
m^2/kg	Meter square per kilogram
w/b	Water/binder
Kg/m^3	Kilogram per meter cube
d	Days
MPa	Mega Pascal
h	Hour
ºC	Degree Celsius
c/c	Centre to centre
Φ	Diameter
N	Newton
KN	Kilo Newton
FA	Fly Ash
CA	Coarse Aggregate
LP	Lime Powder
SP	Super plasticizer
LFS	Ladle Furnace Slag
UPV	Ultra Sonic Pulse Velocity
SCC	Self Compacting Concrete

FR-SCC	Fiber Reinforced Self Compacting Concrete

CHAPTER 1 INTRODUCTION

1.1 General

Self-compacting concrete (SCC) is a fluid mixture, which is appropriate for placing in difficult surroundings and also in congested reinforcement, without vibration. The advancement of self-compacting concrete (SCC) is an advantageous accomplishment in the construction industry in order to beat problems associated with cast-in-place concrete. In principle, a self-compacting or self-consolidating concrete must:

- Have a fluidity that allows self - compaction without external energy
- Remain uniform in a form during and after the placing technique and
- Flow effortlessly through reinforcement. Self compacting concrete is not exaggerated by the skills of workers, the shape and amount of reinforcing bars or the understanding of a structure and, due to its high fluidity and resistance to segregation it can be pumped longer distances (Bartos, 2000).

The addition of fibers into SCC may make improvement of extending the prospect of field application of SCC (Grunewald and Walraven, 2001). The substitute of conventional concrete totally or to some extent with fibers will improve the construction development. Using the reinforcement bars in the construction of concrete structures has a substantial economic impact on the cost of construction (Cunha et al., 2008). It is likely to lessen the energy consumption, better working environment, with concentrated noise and health hazard (Ferrara et al., 2007), however fibers are known to significantly affect the workability of concrete (Grunewald and Walraven, 2001). Designing a appropriate fiber reinforced (FR)-SCC is not an easy job. Several investigations were approved out in order to get the proportions of fiber reinforced (FR)-SCC (Felekoglu et al., 2007). In order to improve and expand the ability of SCC and FR-SCC to flow and to be able to keep its workability within the addition of steel fibers, superplasticizer was used.

Okamura and Ouchi have reported that the coarse and fine aggregate contents can be kept constant to obtain the self-compatibility easier by adjusting the water/cement ratio and the superplasticizer quantity only (Okamura and Ouchi, 1999; Felekoglu et al., 2007).

1.1.1 History after development of SCC

The latest purpose of self-compacting concrete (SCC) is paying attention on high performance, better and more reliable and consistent quality. Self-compacting concrete, in standard, is not new. The particular applications such as underwater concreting have always requisite concrete, which might be located without want for compaction (Bartos, 2000). In such circumstance vibration was simply impractical. Early self compacting concretes relied on very high contents of cement paste and, once super plasticizers became accessible, they were supplementary in the concrete mixes. The mixes required specific and well-controlled placing methods in order to keep away from segregation, and the high contents of cement paste made them prone to shrinkage. In general costs were very high and applications remained very restricted.

The introduction of “recent” self-leveling concrete or self-compacting concrete (SCC) is linked with the force towards improved quality concrete pursued in Japan around 1983, where the lack of homogeneous and full compaction had been recognized as the main factor accountable for poor performance of concrete structures, (Dehn et al., 2000). This led to the expansion of the first workable SCC by researchers Okamura and Ozawa (1986) at the University of Tokyo and the large Japanese contractors (e.g. Kajima Co., Maeda Co., Taisei Group Co., etc.) promptly took up the idea. In the early 1990’s there was only an incomplete communal knowledge about SCC, mainly in the Japanese language. The SCCs were used under trade names, such as the NVC (Non-vibrated concrete) of Kajima Co., SQC (Super quality concrete) of Maeda Co. or the Biocrete (Taisei Co.). Simultaneously, with the Japanese developments in the SCC area, research and development sustained in mix-design and placing of underwater concrete where new admixtures were producing SCC mixes with performance corresponding that of the Japanese SCC concrete (e.g. University of Paisley/Scotland, University of Sherbrook/Canada), (Ferraris,1999). SCC has proved advantageous cost-effectively because of a number of factors as noted below (Krieg, 2003; and ENFARC, 2002):

- Faster construction,
- Lessening in site manpower,
- Easier placing,
- Uniform and complete consolidation,

- Improved surface finishes,
- Enhanced durability,
- Improved bond strength,
- Superior freedom in design
- Reduced noise levels, due to lack of vibration, and
- Secure working environment.

1.1.2 Objective behind advancement of SCC

Recognizing the need of homogeny and whole compaction of concrete by vibration, researchers at the University of Tokyo, Japan, started in late 1980's to develop SCC. By the early 1990's, Japan has developed and used SCC that does not need vibration to attain full compaction. By the year 2000, the SCC has become popular in Japan for prefabricated products and ready mixed concrete. The use of self compacting concrete started rising speedily.

The added aim was to reduce durability problems in complicated and heavily reinforced concrete structures due to lack of skilled workers and a poor communication between designers and construction engineers.

As a result of this fact, one solution for the achievement of durable concrete structures independent of the quality of construction work was the employment of self compacting concrete, which could be compacted into every corner of a formwork, purely by means of its own weight. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, were accepted out by researchers Ozawa and Maekawa at the University of Tokyo (Bartos, 2000). By emergent concrete that self-consolidates, they eliminated the main cause for the poor durability performance of the concrete.

1.1.3 Construction incorporating SCC

By employing SCC, the cost of chemical and mineral admixtures is remunerated by the removal of vibrating compaction and work completed to level the surface of the normal concrete, (Khayat et al., 1997). However, the total cost for a certain construction cannot always be condensed, because conservative concrete is used in a greater percentage than self-compacting concrete. SCC can greatly get better construction systems formerly based on conservative concrete requiring vibrating compaction. Vibration compaction, which can effortlessly cause segregation, has been an obstruction to the validation of construction work. Once this problem has been eliminated, concrete construction could be rationalized and a new construction arrangement, counting formwork, reinforcement, support and structural design, could be developed.

The main reasons for the employment of SCC can be summarized as follows:

- To curtail construction time.
- To declare compaction in the structure - especially in restricted zones where vibrating compaction is not easy.
- To eliminate noise due to vibration - efficient especially at concrete products plants.

The method for achieving self-compact capacity involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the restricted zone reinforcing bars (Okamura and Ouchi, 2003).

Okamura and Ozawa (2003) have employed the subsequent methods to attain self compact ability:

- Limited aggregate content
- Low water-powder ratio
- Use of super plasticizer

Because of the accumulation of a high quantity of fine particles, the internal material structure of SCC shows some similarity with high performance concrete having self compact ability in fresh phase, no early defects in early stage and defense against external factors after hardening.

Due to the lower content of coarse aggregate, however, there is some apprehension that:

- SCC may have a lower modulus of elasticity, which may affect deformation characteristics of pre stressed concrete members and
- Creep and shrinkage will be higher, affect pre stress loss, long-term deflection (Mata, 2004).

SCC can be formed by ordinary cements and additives. It consists mainly of cement, coarse and fine aggregates, and filler, such as fly ash or super pozzolans, water, super plasticizer and stabilizer. The composition of SCC is comparable to that of normal concrete but to achieve self flow ability admixtures, such as fly ash, glass filler, limestone powder, silica fume, rice husk ash, super pozzolans etc; with some super plasticizer is assorted. Figure 1.1 shows the comparison of conventional and SCC constituents.

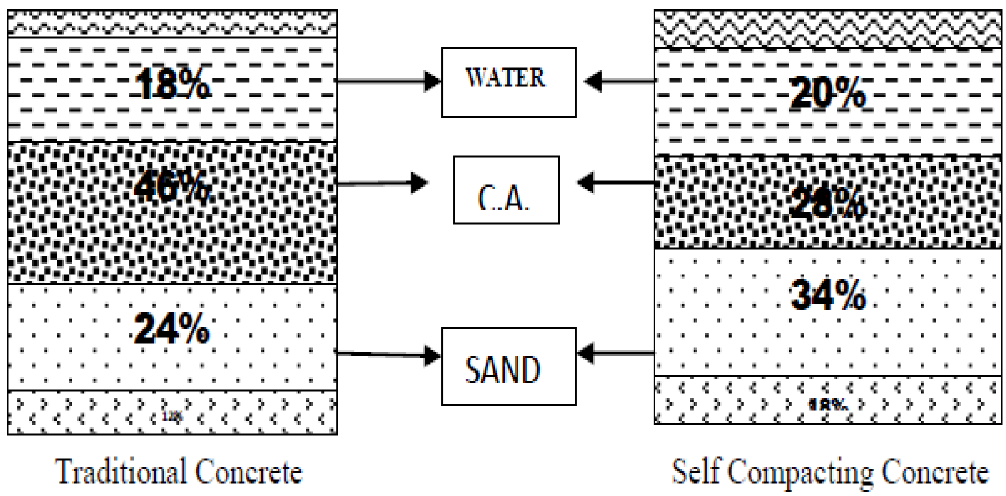

Figure 1.1: Comparison of Traditional and SCC constituents

Three essential characteristics that are required to obtain SCC are:

- **High deformability** - associated to the capacity of the concrete to deform and widen freely in order to fill all the gaps in the formwork. It is generally a task of the form, size, and quantity of the aggregates, and the friction between the solid particles, which can be condensed by addition a high range water-reducing (HRWR) admixture.
- **Restrained flow ability** - represents how effortlessly the concrete can flow around obstacles, such as reinforcement, and is linked to the member geometry and the shape of the formwork.
- **A high resistance to segregation -** related to the cohesiveness of the fresh concrete, which can be improved by adding up a viscosity-modifying admixture (VMA) along with a HRWR admixture, by reducing the free-water content, by rising the volume of paste, or by some combination of these constituents. (Khayat et al., 2004). Figure1.2 shows basic principles for the manufacture of SCC.

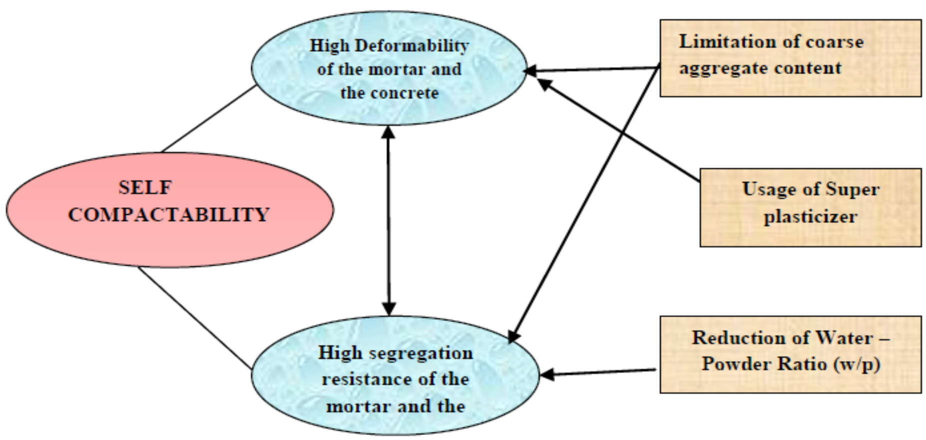

Figure 1.2: Basic principles for the production of SCC (Dehn et al., 2000)

1.1.4 World-wide present state of SCC

SCC has by now been used in several countries. In Japan, major construction projects incorporated the use of SCC in the late'90s. Today in Japan, efforts are being made to free SCC of the "special concrete" label and integrate it into day to day concrete industry manufacture

(Okamura, 1997). At present, the percentage of self compacting concrete in yearly product of ready-mixed concrete (RMC), as well as precast concrete (PC), in Japan is approximately 1.2 and 0.5% of concrete products.

The beginning of the SCC in Europe is mainly linked with the activities of the international association RILEM France, chiefly of its Technical Committee TC145-W S M on “Workability of Fresh Special Concrete Mixes” (Dhir et al., 1999). The TC145-WSM was founded in 1992 and without delay attracted expert memberships from all over the world. The aspire was to look at the production stage of a number of “special” concretes and know workability parameters and additional characteristics of the mixes in their fresh state that governed the consistent and cost-effective accomplishment of the “special” or “high -performance” parameters the concretes presented. As the significance of the SCC became widely known, other European countries, Germany, Sweden, UK, Denmark, Netherlands, Norway, Finland, etc., have determined to keep up with the developments in this area. For example, in Sweden, the SCC markets contribute to be at five percent in RMC and PC in 2002, and were predictable to double in 2003. Housing and tunneling, in addition to bridge construction for the Swedish National Road Administration were the major areas of use for SCC. In Netherlands and Germany, the precast industry is mostly driving the development of SCC, with a predictable eight percent of market share in 2003 in Netherlands.

Nowadays, SCC is being considered worldwide, with papers presented at about every concrete-related conference, but after year 2003 there is no universally adopted standardized test method for assessment of self-compact ability of this concrete. At present, the use of self-compacting concrete is being speedily adopted in many countries. The use of self-compacting concrete should conquer concrete placement problems associated with the concrete construction industry. However, there still is a need for conducting added research and development work for the measurement and regularity of the methods for the evaluation of the self compacting characteristics of SCC.

1.2 Benefits and Advantages

At present, SCC can be classified as an highly developed construction material. The SCC as the name suggests, does not want to be vibrated to attain full compaction. This offers benefits and advantages greater than conventional concrete.

- Enhanced quality of concrete and reduction of onsite repairs.
- Quicker construction times.
- Lower on the whole costs.
- Facilitation of opening of mechanization into concrete construction. Development of health and safety is also achieved through removal of handling of vibrators.
- Considerable reduction of environmental noise loading on and around a site.
- Possibilities for employment of "dusts", which are currently waste products and which are expensive to dispose of.
- Improved surface finishes.
- Easier placing.
- Thinner concrete sections.
- Superior freedom in design.
- Enhanced durability, and reliability of concrete structures.
- Easiness of placement consequences in cost savings through reduced equipment and labour requirement.
- SCC makes the level of durability and reliability of the structure free from the existing on site conditions relate to the quality of labour, casting and compacting systems available.
- The high resistance to external segregation and the mixture self- compacting ability permit the eradication of macro-defects, air bubbles, and honey combs responsible for disciplining mechanical performance and structure durability.

1.3 Secondary Raw Materials (SRMs)

SRMs are mostly cementitious materials, fillers, powders depending upon their function in fresh and hardened state. SRMs help in development of hydration and especially in improving the hydration product. They usually substitute part of cement. These mostly include limestone powder (LSP), fly ash (FA), ground granulated blast furnace slag (GGBS), silica fumes (SF) and rice husk ash (RHA). SRMs are too called mineral admixtures, contributing towards properties of hardened concrete through physical and chemical properties as well as hydraulic or pozzolanic activity. These materials act in response chemically with calcium hydroxide released from hydration of Portland cement to form cement compounds. These materials often added to concrete to make concrete mixtures more inexpensive, decrease permeability, increase strength or control other concrete properties.

1.3.1 Advantages of using SRMs

The utilization of supplementary cementing materials can considerably improve durability properties, transport properties of concrete. On the other hand different dosages and combinations of supplementary materials give way dramatically dissimilar results. The use of SRMs in concrete may bring lot's of benefits like enlarged flow and strength, decreased shrinkage , reduced water demand (WD) etc. but some troubles may also be caused.

1.3.2 Utilization of fly ash as filler material

Fly ash has been used as a highly reactive pozzolanic material to advance the microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in self compacting concrete. Mechanical experiments of fly ash blended Portland cement concretes discovered that in addition to the pozzolanic reactivity of fly ash (chemical aspect), the particle grading (physical aspect) of cement and fly ash mixtures as well exerted important influences on the blending efficiency. The utilization of fly ash (FA) reduces the demand of cement, fine fillers and sand required for SCC.

Fly ash, a by-product of coal power plants, has been reported to advance mechanical properties such as freeze–thaw resistance, sulphate resistance, alkali–silica reaction, durability and abrasion resistance when it has been used as a cement substitute material in mortar and concrete. In addition, shrinkage and permeability of hardened concrete are decreased due to filling of micro pores. Utilization of fly ash in concrete technology is becoming more widespread - also because fly ash reduces the chloride penetration and steel corrosion in concrete. Two familiar causes of corrosion in concrete are associated to localized breakdown of passive films on steel by chloride ions and by reaction with atmospheric carbon dioxide. Generally chlorides penetrate into concrete by diffusion beside water paths or open pores. Some of these chlorides can react with the cement compounds, mainly tricalcium aluminates, forming stable chloro complexes. The presence of FA leads to an augment in the amount of tricalcium aluminates present and also an increase in the content of calcium silica hydrate produced in pozzolanic reactions. As a result, there are fewer free chlorides accessible to initiate corrosion. Silica hydrate formed in pozzolanic reactions. Thus, there are less free chlorides available to start corrosion (Gencel et al., 2011).

1.4 Steel Fibers

This study focuses on steel fibers. They operate as crack arrestor in concrete. Steel fiber length ranges from 1/4 to 3 inches (1.5 to 75 mm) and aspect ratio ranges from 30 to 100. Fiber shapes are illustrated below in Figure 1.3.

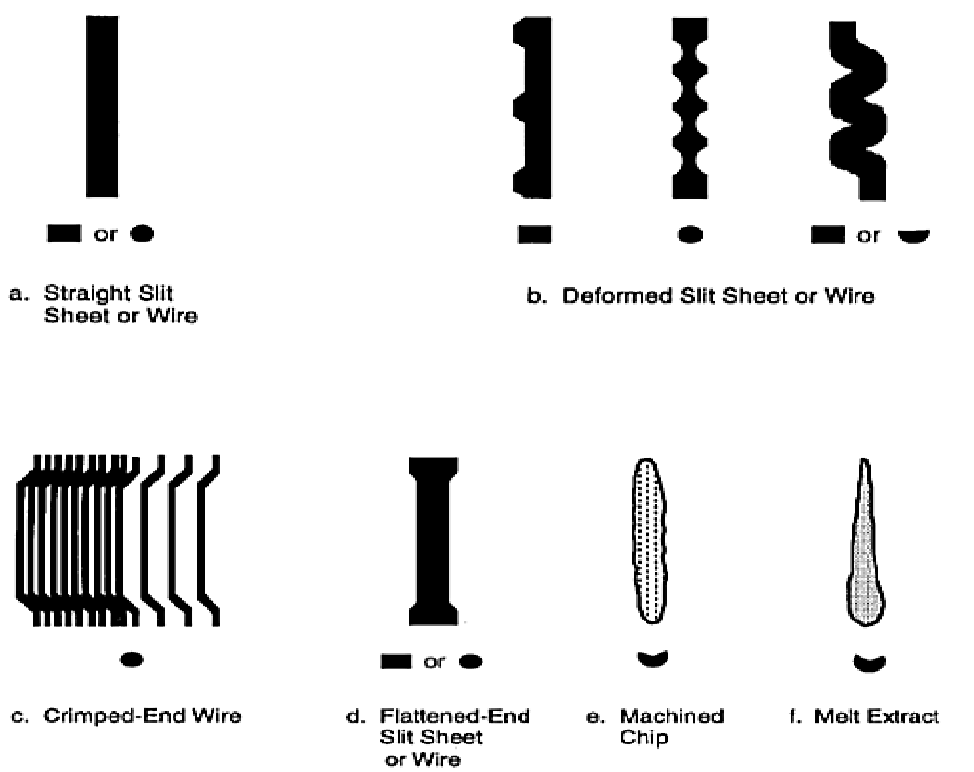

Figure 1.3: Steel fiber types with different geometric properties (ACI 544.1, 1996)

1.4.1 Types of steel fibers

Fibers are in a range of sizes and shapes. Round steel fibers prepared up of low-carbon steel or stainless steel, having diameters in the range of 0.25 to 1 mm. Flat steel fibers, formed by shearing sheet or flattening round wire and are accessible in thicknesses ranging from 0.15 to 0.41 mm. Crimped and deformed steel fibers are obtainable both in full length or crimped at the ends simply. A typical volume fraction of steel fibers is 0.25 to 1.5% (of the volume of concrete) (Somayaji, 2001). Comprehensive sketches of some of steel fiber types are as revealed in Figure 1.3.

1.4.2 Properties of fibers

A good fiber is the one which own the following qualities:

- Good adhesion surrounded by the matrix.
- Adaptable elasticity modulus (sometimes higher than that of the matrix).
- Compatibility with the binder, which should not be attacked or damaged in the long term.
- A reachable price, taking into account the proportion contained by the mix.
- Being satisfactorily short, fine and flexible to allow mixing, transporting and placing.
- Being sufficiently strong, yet sufficiently strong to withstand the mixing process.

1.4.3 Aspect ratio

Aspect ratio is defined as the ratio of length to width of the fiber. The value of aspect ratio varies from 30 to 150. Usually, the increase in aspect ratio increases the strength and stiffness till the aspect ratio of 100. Beyond that the strength of concrete decreases, in sight of decreased workability and concentrated compaction. On or after investigations, it can be found out that good results are obtained at an aspect ratio around 80 for steel fibers.

1.4.4 Fiber quantity

Commonly, quantity of fibers is calculated as percentage of cement content by weight. As the volume of fibers increase, as a result augment in strength and toughness of concrete occurs.

1.4.5 Orientation of fiber

The orientations of fibers play a key function in formative the capacity of concrete. In RCC, the reinforcements are positioned in desired direction. But in FRC, the fibers will be oriented in random direction. The FRC will have maximum resistance whilst fibers are oriented parallel to the load applied.

1.5 Fiber Mechanism with Concrete

Fiber employ with concrete utilizing two mechanisms: the spacing mechanism and the crack bridging mechanism. The spacing mechanism requires a large quantity of fibers well distributed contained by the concrete matrix to arrest any existing micro crack that could potentially enlarge create a sound crack. For typical volume of fractions of fibers utilizing small diameter of fibers or micro fibers can make sure the required number of fibers for micro crack arrest. The second mechanism termed crack bridging requires larger straight fibers with adequate bond to concrete. Steel fibers are considered a prime instance of this fiber type that is usually referred as large diameter fibers or micro fibers.

1.5.1 Fiber- matrix interaction

The tensile cracking strain of cement matrix is to a great extent lower than the yield or ultimate strain of fibers. As a consequence, when a fiber reinforced composite is loaded the matrix will crack long before the fibers can be fractured. Once the matrix is cracked composite continues to hold increasing tensile stress. The peak stress and strain of the concrete composite are better than those of the matrix alone during the inelastic range between first cracking and the peak. Multiple cracking of matrix occurs as indicated in Figure1.4.

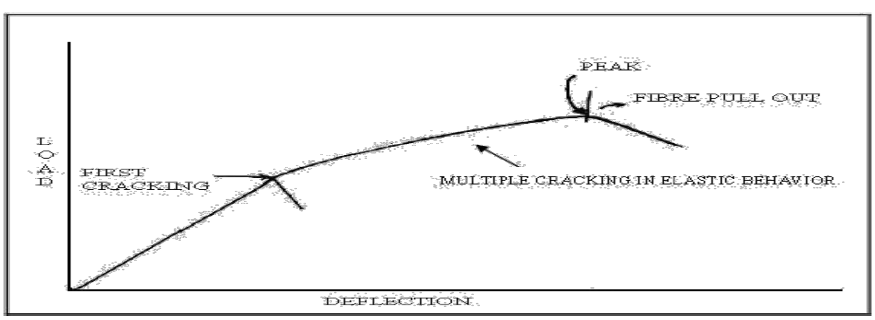

Figure 1.4: Fiber mechanism (Somayaji, 2001)

1.5.2 Bridging action:

Pullout resistance of fibers (dowel action) is vital for effectiveness. Pullout strength of fibers considerably improves the post-cracking tensile strength of concrete. As an FRC beam or other structural element is loaded, fibers bridge the cracks. Such bridging action provides the FRC specimen with larger ultimate tensile strength and, more significantly, larger toughness and improved energy absorption. Figure 1.5 shows the pull out mechanism.

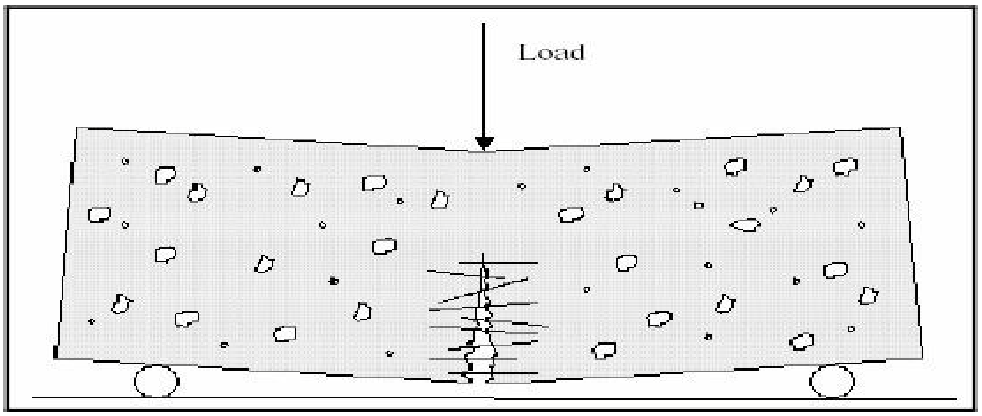

Figure 1.5: Pullout mechanism (Somayaji, 2001)

1.6 Fiber Reinforced Self-Compacting Concrete (FR-SCC)

The removal of vibration for the compaction of fresh concrete makes the utilization of self-compacting concrete (SCC) advantageous in stipulations of cost reduction and development of the work environment. In addition, due to its intrinsic low porosity, SCC usually has high performance properties also in requisites of mechanical behavior and durability. These properties could even be elevated improved if steel fibers are integrated, thus obtaining FR-SCC (Torrijos et al., 2007).

The adding of fibers into self-compacting concrete may take benefit of its high performance in the fresh state for homogeneously dispersal within the matrix as well as many advantages like the development in the economic efficiency of the construction procedure, increased speed of construction, decrease or suitably focused rearrangement of labor resources, costs and energy consumption, better working environment, with condensed noise and health hazards, also the role toward the automation and reliability of quality control (Ferrara et al., 2007).

The use of fibers might expand the possible fields of application of SCC. Fibers are formed in a wide range of materials, at different shapes, with divergent prop or stiff, cylindrically, rectangular or irregular shaped. They are recognized to affect the workability and the flow characteristics of plain concrete basically. A high content of fibers is not easy to distribute uniformly; a good distribution, however, is required to achieve most favorable benefits of the fibers. Manufactures try to look up the pull-out resistance of the fibers by deforming or crimping them, giving them a surface texture that increases the roughness, in addition to bend or increase the ends to improve the anchorage capacity (Grunewald and Walraven, 2001).

Steel fibers and micro-filler materials are extensively used in the construction industry. These materials augment the performance of self-compacting concrete, consisting of very fine powder. Studies proved that these materials advance the quality of the concrete both in fresh and hardened states. As the volume of the micro-filler materials increases, the distance between the large sizes aggregates also increases, dropping the internal friction of the concrete. Since the blockage of the large aggregates is not permitted, the flow and workability properties of the fresh concrete are improved. The developed volumetric water-to-powder ratio method enables the use of binding materials successfully and provides a tool for optimization, as well as new areas for study on the interaction between the microstructure and mechanical properties of the concrete (Sengul et al., 2006).

1.6.1 Mix design of FR-SCC

A fiber reinforced self-compacting concrete be supposed to be extremely workable concrete lacking bleeding or segregation. The slump loss should also be well controlled. To assure those requirements, materials had to be carefully chosen and their proportion optimized (Miao et al., 2003). The mix design of fiber reinforced self-compacting concrete includes fine materials such as cement, fine aggregates and limestone powder, as well as pozzolanic materials such as fly ash and steel fibers.

Viscosity modifying agents and plasticizers, based on polycarboxylate ether complex, naphthalene sulphonates or melamine sulphonates, are additional added to the mixtures, depending on the properties of the targeted workability. The aim of the mixture design is to obtain the preferred workability and segregation resistance. This mixture should be able to flow approximately the steel reinforcement and should not segregate or clump. For this cause, the water/powder ratio and aggregate gradation be supposed to be controlled, and efficient admixtures should be used during the assembly of self-compacting concrete (Sengul et al., 2006).

1.6.2 Fresh properties of FR-SCC

Steel fiber reinforced concrete can be very stiff in fresh state. Long thin fibers (l/d>100) tend to mat collectively while short stubby fibers (l/d<50) cannot interlock and can be detached by vibration (Gambhir, 1990). A particular fiber type, orientation and percentage of fibers, the workability of the mix decreased as the size and quantity of aggregate particles larger than 5 mm enlarged; the occurrence of aggregate particles less than 5 mm in size had slight effect on the compacting characteristics of the mix (Chanh, 2005).

The workability of fiber reinforced concrete is also biased by maximum size of aggregate. As the size of aggregate increases it becomes more difficult to achieve homogeneous fiber dispersion, while the fibers are bunched into mortar fraction which can move about freely past the fibers throughout compaction. To obtain an improved dispersion the coarse aggregate content is kept lower than to 10 mm.

1.6.3 Durability design consideration of FR-SCC

In conventional mixture design, concrete workability is determined by the water amount and the compressive strength, while the durability is determined by the water-to-cement ratio (ACI 211.1, 1991). The workability can be enhanced by increasing the water amount and the strength can be improved by increasing the cement content. However, too much cement paste will origin large slump loss and bleeding as well as segregation; furthermore, the hydration of the cement will cause chemical shrinkage, and the shrinkage rate or expansion rate is in straight proportion with the water and the cement amounts. Besides, ordinary concrete contains water at slightest 20% of the concrete volume, and therefore drying shrinkage cannot be avoided. Thus the durability of concrete is damaged, due to disintegration and crack formation. To keep away from these problems, a concrete mixture designed with low water amount and low cement content is recommended (Chih-Ta et al., 2009).

Durability design is supposed to be considered for improving both the fresh and hardened stages of the concrete and should finally expand their service life. Primarily the concrete mix design should have a very low water amount so as to reduce the shrinkage rate or the expansion rate of concrete, Then, the concrete must be considered to satisfy the construction needs such as low slump concrete (e.g. roller compacted concrete) or high slump concrete (e.g. self-compacting concrete, high performance concrete), type of construction work, and the mandatory final finished result. In the plastic stage, the fresh concrete is designed to prevent the rate of plastic shrinkage cracks due to surplus water evaporation from the concrete surface. A certain quantity of steel fiber should be included in the concrete mix to soak up energy and in the case of crack formation, to stop their propagating. The addition of pozzolanic materials is obligatory to help the self-healing of cracks if they are generated. A firm standard procedure for mixture proportion, material selection, trial batch, quality control, and curing are requisite to lower the possibility of crack formation (Chih-Ta et al., 2009).

1.7 Properties and Tests

1.7.1 Properties

Fresh SCC must own at required levels the following key properties:

- **Filling ability:** This is the ability of the SCC to flow into all spaces inside the formwork under its own weight.
- **Passing ability:** This is the ability of the SCC to flow from beginning to end tight openings such as spaces between steel reinforcing bars, under its own weight.
- **Resistance to segregation:** The SCC must meet up the requisite levels of properties A and B at the same time as its composition remains uniform throughout the process of transport and placing.

Figure 1.6 shows schematic ways to achieve SCC.

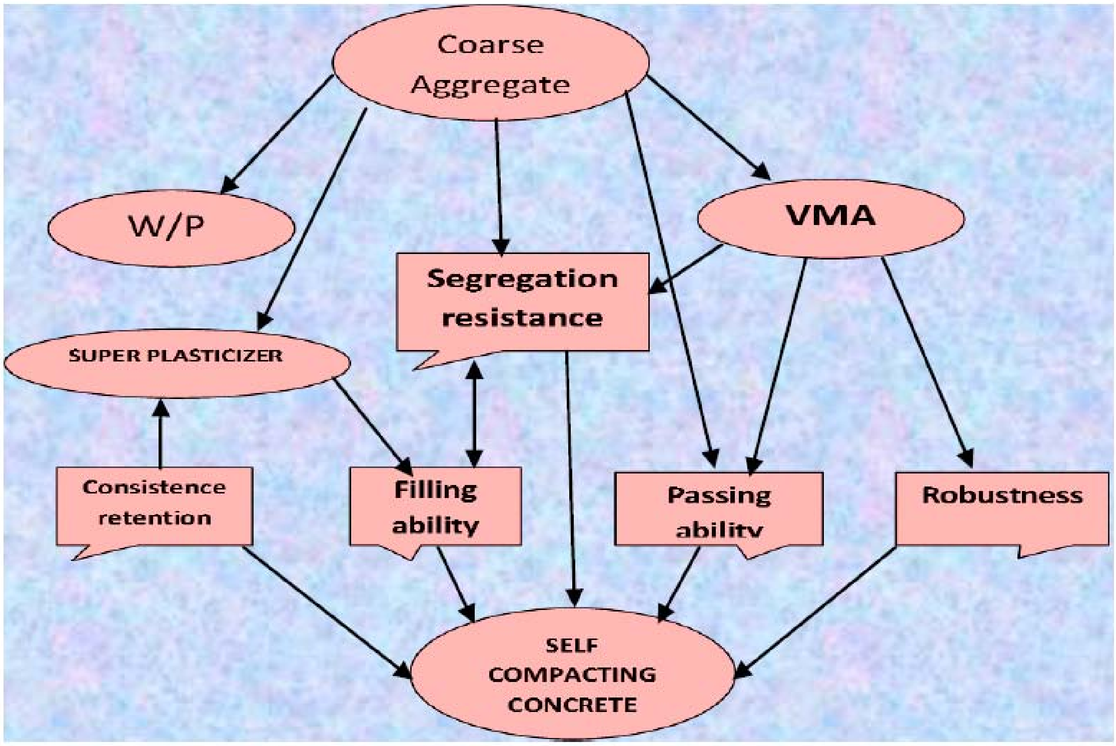

Figure 1.6: Schematic way to achieve SCC

1.7.2 Tests

Some of the key tests conducted on fresh SCC to assess its workability are summarized in Table 1.1 and are briefly explained later.

Table 1.1: Test methods to evaluate the workability properties of SCC (EFNARC, 2002)

Property	Test Methods	
	Field (Quality Control)	
Filling Ability	Slump Flow Test T_{50cm} Flow Test V- Funnel Test Orimet Test	Slump Flow Test T_{50cm} Flow Test V- Funnel Test Orimet Test
Passing Ability	L-Box Test U-Box Test Fill Box Test	J Ring Test
Segregation Resistance	GTM Test V-Funnel At $T_{5\ Mins}$	GTM Test V-Funnel At $T_{5\ Mins}$

1.7.2.1 Slump flow test

The slump flow test is used to evaluate the horizontal free flow of self compacting concrete in the absence of obstructions. The equipments used are the similar as for the conventional Slump test. The test method differs from the conventional one by the fact that the concrete sample located into the mould is not rodded and when the slump cone is detached the sample collapses, (Ferraris, 1999). The diameter of the spread of the sample is calculated, i.e. a horizontal space is determined as opposed to the vertical distance in the conventional Slump test. The Slump flow (Figure 1.7) test can present an indication as to the consistency, filling ability and workability of SCC. The SCC is assumed of having a good filing ability and uniformity if the diameter of the spread reaches values between 650 to 800 mm (EFNARC, 2002).

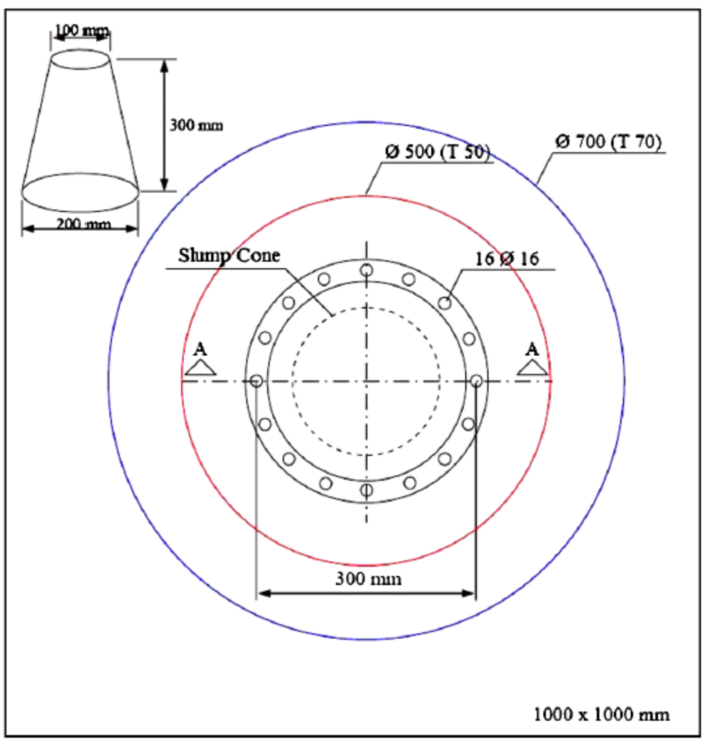

Figure 1.7: Slump flow test (Gencel et al., 2011)

1.7.2.2 U- box test

Of the various testing methods used for evaluating self-compact ability, the U- box test (Figure 1.8) planned by the Taisei group is the most suitable, due to the small amount of concrete used, compared to others, (Ferraris, 1999). This test is used to determine the filling ability of SCC. The apparatus consists of a vessel that is separated by a middle wall into two compartments. It provides a good direct judgment of passing ability.

For conducting the U-box test, one of the compartments of the equipment is filled with the concrete sample and packed concrete is left to stand for 1 min. Then the sliding gate is lifted to permit the concrete to flow out into the other compartment. Subsequent to the concrete comes to rest, the height of the concrete in the compartment that has been filled is measured in two places and the mean height (H1) is considered. Also the height in the other compartment (H2) is measured. The filling height is then calculated as H1- H2. The entire test has to be performed within 5 min. If the concrete flows as freely as water, at rest it will be horizontal, so H1- H2 = 0. Therefore, closer this test value, i.e., the filling height is zero, the better the flow the better the flow and passing ability of SCC (EFNARC, 2002).

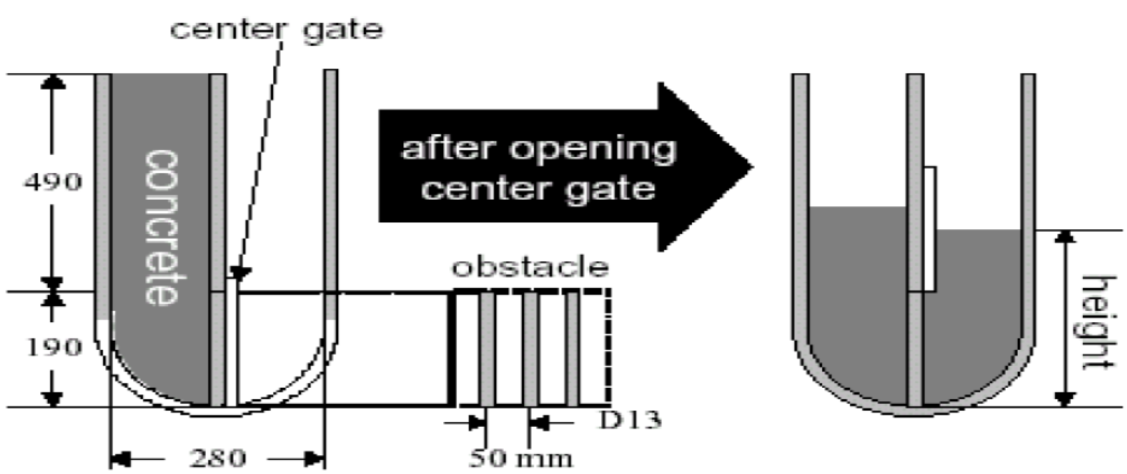

Figure 1.8: U- box test (Gencel et al., 2011)

1.7.2.3 Orimet test

This test is based on the standard of an orifice rheometer useful to fresh concrete, (Bartos, 2000). The test involves recording of time that it takes for a concrete sample to flow out from a vertical casting pipe throughout an interchangeable orifice attached at its lower end. The shorter the flow-time, the higher is the filling ability of the fresh mix. The Orimet test also shows prospective as a means of assessment of resistance to segregation on a site.

1.7.2.4 L- box test

This method uses a test equipment comprising of a vertical section and a horizontal trough (Figure 1.9) into which the concrete is permitted 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 equipment (Gencel et al., 2011). The time that it takes the concrete to flow a distance of 200 and 400mm into the horizontal section is considered, as is the height of the concrete at both ends of the apparatus (H1 and H2). The L-Box test can give an indication as to the filling ability and passing ability.

Figure 1.9: L- box (Google – Images for SCC)

1.7.2.5 V-funnel test

Viscosity of the self-compacting concrete is obtained by using V-funnel equipment, which is shown in Figure 1.10. The time for the quantity of concrete to flow through the orifice is being calculated. If the concrete starts moving through the orifice, it means that the stress is higher than the yield stress. Consequently; this test measures a value that is associated to the viscosity. If the concrete does not move, it shows that the yield stress is larger than the weight of the volume used.

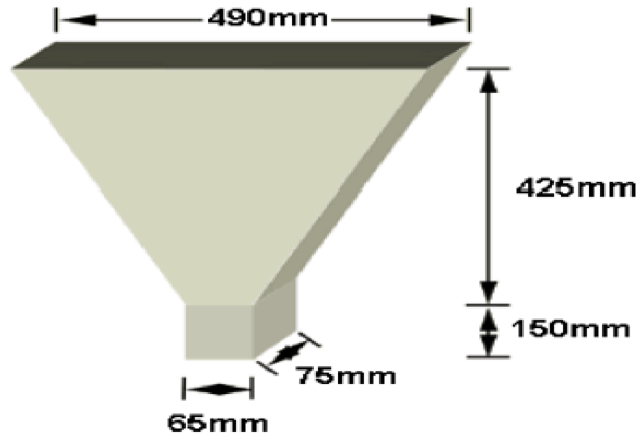

Figure 1.10: V-funnel (Gencel et al., 2011)

Sequentially to make sure that the SCC has not lost its uniformity during transport and placing due to it's highly flow able and self leveling nature, it is optional that the in-situ tests, such as rebound hammer, pull-out, etc. should be conducted. Non-variations in these near-surface properties may be measured as an indication of no loss of uniformity. The size and quantity of coarse aggregates in a SCC mixture are directly correlated to the concrete passing ability. The passing ability requirements depend on the formwork geometry and the degree of congestion of the reinforcement. Risk of blockage is concentrated by providing adequate viscosity. Adequate cohesiveness can be obtained by incorporating a viscosity-modifying admixture (VMA) along with a high range water reducing admixture to control bleeding, segregation, and surface settlement (Khayat et al., 1997).Typical acceptance criteria for SCC with a maximum aggregate size of up to 20 mm are accessible in Table 1.2.

Table 1.2: Acceptance criteria for self-compacting concrete (EFNARC, 2002)

Method	**Minimum Value**	**Maximum Value**
Slump- Flow (mm)	650	800
J- Ring (mm)	0	10
V- Funnel (sec)	6	12
L- Box (H_2/H_1)	0.8	1.0
U- Flow (H2-H1)mm	0	30
Orimet (sec)	0	5
Fill Box (%)	90	100

1.8 Orientation of Thesis Report

This thesis is presented in five chapters as comprehensive under:

Chapter-1 Gives the introduction about self-compacting concrete, steel fiber, steel fiber reinforced SCC.

Chapter-2 Literature review presents the work done by various researchers in the field of self-compacting concrete with steel fibers.

Chapter-3 Details the scheme of experimentation, materials used, and variables involved, concrete mixes, mix design, casting and testing of specimens.

Chapter-4 Gives results of various parameters studied and are compared with control concrete.

Chapter-5 Gives the major conclusions made in the study.

References

2.1 Physical and Chemical Properties of Cement, Fly Ash and Steel Fibers

Various scientists (i.e. Khaloo et al., 2014; Rambo et al., 2014; Kamal et al., 2013; Gencel et al., 2011 and Ferrara et al., 2007) have studied the physical and chemical properties of materials i.e. ordinary Portland cement, fly ash and steel fibers, aggregates. Chemical and Physical properties of Ordinary Portland Cement (OPC) are shown in Table 2.1 and Table 2.2.

Table 2.1: Chemical composition limits of OPC

Chemical Composition	**Content (%)**				
	Khaloo et al. (2014)	**Rambo et al. (2014)**	**Kamal et al. (2013)**	**Gencel et al. (2011)**	**Ferrara et al. (2007)**
Silicon Dioxide (SiO_2)	20.4	17.6	16.39	57.2	17.454
Titanium Oxide (TiO_2)	-	-	-	1.16	0.348
Aluminum Oxide (Al_2O_3)	4.9	3.67	3.85	25.5	4.422
Ferric Oxide (Fe_2O_3)	3.9	3.8	3.48	6.01	3.93
Manganese Oxide (MnO)	-	-	-	-	0.064
Magnesium Oxide (MgO)	1.7	0.78	0.65	2.42	2.346
Calcium Oxide (CaO)	63	69.20	68.48	0.12	65.844
Sodium Oxide (Na_2O)	0.4	0.53	0.06	0.42	0.252
Potassium Oxide (K_2O)	0.5	0.58	0.52	4.60	1.117
Phosphorous Pent Oxide (P_2O_5)	-	-	-	-	0.068
Sulphur Trioxide(SO_3)	2.0	2.4	2.6	0.16	3.979
LOI	-	-	1.7	1.12	-

Table 2.2: Physical properties of OPC

Property	Value				
	Khaloo et al. (2014)	**Rambo et al. (2014)**	**Kamal et al. (2013)**	**Gencel et al. (2011)**	**Ferrara et al. (2007)**
Specific gravity (gm/cm^3)	3.12	3.15	3.15	3.15	3.13
Specific Surface (m^2/g)	2950	3250	3520	4150	3415

Chemical and Physical properties of fly ash are shown in Table 2.3 and Table 2.4.

Table 2.3: Chemical composition of fly ash

Constituents	Content (%)				
	Oleveira et al. (2013)	**Kamal et al. (2013)**	**Gencel et al. (2011)**	**Sahamarn and Yaman (2007)**	**Ferrara et al. (2007)**
Silicon Dioxide (SiO_2)	57.2	31.35	57.2	49.55	59.04
Aluminum Oxide (Al_2O_3)	26.4	16.77	25.5	13.34	34.08
Ferric Oxide (Fe_2O_3)	6.05	5.57	6.01	8.51	2.0
S + A + F	88.7	-	89.0		0.22
Manganese Oxide (MnO)	1.2	23.26	1.14		0.05
Magnesium Oxide (MgO)	2.8	5.42	2.42	4.10	0.43
Titanium Oxide (TiO_2)	1.67	-	1.16		-
Sulphur Trioxide(SO_3)	0.12	2.02	0.16	1.70	-
Potassium Oxide (K_2O)	4.7	0.31	4.6	1.99	0.76
Sodium Oxide (Na_2O)	0.46	2.07	0.42	3.08	0.5
Chlorine (Cl)	0.012	0.13	0.014		-
LOI	1.25	-	1.12	2.74	0.13
Calcium Oxide (CaO)	0.15	-	0.12	11.31	-

*S + A + F = $SiO_2 + Al_2O_3 + Fe_2O_3$

Table 2.4: Physical properties of Fly ash

Property	Value				
	Kamal et al. (2013)	**Oleveira et al. (2013)**	**Gencel et al. (2011)**	**Ferrara et al. (2007)**	**Sahamarn and Yaman (2007)**
Specific Gravity (gm/cm^3)	2.1	1.98	1.975	2.1	1.967
Colour	Grey	Dark Grey	Dark Grey	Grayish Black	Grey

Properties of Steel Fibers are shown in Table 2.5.

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Table 2.5: Properties of hooked steel fibers

Properties	Value				
	Rambo et al.(2014)	**Anastasiou et al. (2014)**	**Kamal et al. (2013)**	**Gencel et al. (2011)**	**Ferrara et al. (2007)**
Length (mm)	30	30	30	30	13.8, 23, 32.2
Diameter (mm)	0.5	0.5	0.5	0.5	0.92
Aspect Ratio (l/d)	60	60	60	60	15, 25, 35
Tensile Strength(MPa)	$1.19x10^3$	1200	$1.25x10^3$	1100	331
Elasticity Modulus (MPa)	-	-	$2.0x10^5$	-	-
Specific Gravity (g/cm^3)	7.76	7.68	7	7.48	7.850

2.2 Properties of Study

2.2.1 Fresh concrete properties

Kamal et al. (2013) prepared five mixes with 10 mm maximum size of aggregate and four mixes with 14 mm maximum size of aggregate. For the experiment, he took 400 kg/m^3 cement and fly ash content each for all ten mixes with different proportions of coarse aggregate and sand with w/p ratio 0.35 for 8 mixes and 0.4 for ninth mix along with various percentages of HRWR admixture ranging from 2 to 3.5%.

From fresh concrete results, it was observed that only Mix No. 9 satisfies the requirements of technical specifications of SCC. Based on test results of Mix No. 9, three mixes were prepared with different percentages of steel fibers. The concrete mix proportions of 4 mixes with max. Aggregate size 14mm are shown in Table 2.6

Table 2.6: Concrete mix proportions (kg/m^3) (Kamal et al., 2013)

Size of Coarse Aggregate	Mix No.	Cement	Sand	Dolomite	Fly ash	W/P	Steel fiber (%)	HRWR (%)
14mm	9	400	920	752	40	0.4	0	2
	SSCC1(10)	-	972	862	-	-	0.5	2.5
	SSCC2(11)	-	972	860	-	-	0.75	3
	SSCC3(12)	-	968	859	-	-	1.0	3.25

The rheological properties of fiber self compacting concrete mixes are shown in Table 2.7.

Table 2.7: Rheological properties of fiber SCC mixes (Kamal et al., 2013)

Mix No.	D (mm)	T_{500} (sec.)	J-Ring Test(H1-H2)	V- Funnel, T_v (sec.)
9	750	4.57	3.5	6.25
SSCC1(10)	730	18.17	2	10.26
SSCC2(11)	700	4.89	4	11.2
SSCC3(12)	625	2.2	25	13.37

The basic requirements of flow ability as specified by technical specifications of SCC found satisfactory by SSCC2 (11) mix as compare to control mix. The flow diameter 700 mm and flow time at 50 cm was found 4.89 sec. Also, the V-Funnel passing time was 11.2 sec for SSCC2 (11) having steel fibers 0.75% by volume.

Rambo et al. (2014) studied the rheological properties of SCC with the addition of two types of steel fibers. One straight (SF1) and one with hooked ends (SF2).Five concrete mixtures with proportions are presented in the Table 2.8.

Table 2.8: Mix composition of SCC (Rambo et al., 2014)

Constituents	Matrix	C1.0%H	C1.0%	C1.5%H	C1.5%
CA (kg/m^3)	494	494	468	454	454
Sand(S1)	830	830	830	830	830
Sand(S2)	100	100	100	100	100
Silica Mesh	70	70	70	70	70
Cement(kg/$m^{3)}$	360	360	360	360	360
Fly ash	168	168	168	168	168
Silica Fume	45	45	45	45	45
SP	45.1	45.1	45.1	45.1	45.1
VM	0.36	0.36	0.36	0.36	0.36
Water	150	150	150	150	150
SF1	0	0	39	0	39
SF2	0	0	39	78	0
SP (%)	4	4	4	4	4
w/b	0.5	0.5	0.5	0.5	0.5

With the addition of steel fibers, all concrete mixes had adequate viscosity and deformability under their own weight. The slum flow is observed in range of 620-720 mm which is as per limits given by EFNARC (2005). The unreinforced mix and concrete mix prepared with 1% fibers i.e. C1.0% and C1.0%H also meet the EFNARC specification for viscosity (V-funnel) and passing ability (L-box).The concrete with 1.5% hooked steel fibers was found blocked in V-funnel and L-box Test with two bars. The fresh concrete properties are shown in Table 2.9.

Table 2.9: Results of rheological tests (Rambo et al., 2014)

Mixture	Spread (mm)	V-Funnel (sec)	L-Box (mm)	Viscosity
Matrix	620	18.15	0.95	187
C1.0%H	705	18.39	0.95	230
C1.0%	720	19.25	1.0	157
C1.5%H	620	BL	BL	341
C1.5%	700	19.56	0.5	156

Anastasiou et al. (2014) prepared three series of test mixtures A, B, C with the incorporation of hooked steel fibers of length 30 mm and aspect ratio 60 .The mix proportions of SCC are given in Table 2.10.

Table 2.10: Self compacting mixture composition (Anastasiou et al., 2014)

Components(kg/m^3)	**A-1**	**A-2**	**A-3**	**B-1**	**B-2**	**B-3**	**C-1**	**C-2**	**C-3**
Cement	350	350	350	350	350	350	350	350	350
Ladle Furnace Slag	60	60	60	60	60	60	60	60	60
Aggregate powder	40	40	40	90	90	90	120	120	120
Total Powder	450	450	450	480	480	480	510	510	510
w/c	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
w/p	1.04	1.04	1.04	0.98	0.98	0.98	0.92	0.92	0.92
FA (%)	50	50	50	50	50	50	50	50	50
Steel Fibers (%)	0	0.4	0.7	0	0.4	0.7	0	0.4	0.7
SP (%)	1.5	1.5	2	1.5	2	2	2	2	2
VMA	0	0.4	0.4	0	0.2	0.4	0	0.4	0.4

The self compact ability of concrete fresh mixtures was assessed by measuring slum flow, T_{500} sec, L-box for passing ability segregation resistance. The test results of fresh concrete properties are shown in Table 2.11.

Table 2.11: Fresh concrete properties (Anastasiou et al., 2014)

Property	**A-1**	**A-2**	**A-3**	**B-1**	**B-2**	**B-3**	**C-1**	**C-2**	**C-3**
Slump flow(mm)	580	570	540	570	540	500	600	570	560
T500 (SEC)	7	9	7	8	8	9	9	4	6
L-box(mm)	0.8	0.78	0.8	0.8	0.83	0.78	0.79	0.8	0.8
Segregation resistance (%)	7.8	7.9	14	2.5	7	12	1	3.6	9

It was observed that the slump flow is adequate in all mixes i.e. in range 500-600 mm but clearly decreases with increase of fiber content. Despite higher dosage of chemical admixtures, all mixes showed values higher than 4 sec for T500 sec test which correspond to higher viscosity in SCC. Regarding the passing ability, L-box ratios are also low in all cases which means that all mixes are marginally considered Self compacting concrete mixes, since EFNARC (2005) suggests L2/L1 ratio greater than 0.8

Segregation resistance values of all mixes are found below 1.5% which is the limit as per EFNARC (2005). From rheological properties of mixes it is concluded that higher amount of ladle furnace slag as powder can compensate for the increased segregation due to the use of fibers.

Sahmaran and Yaman (2007) prepared five mixes for the study and composition is given in Table 2.12. Fly ash is replaced with 50% of cement content. SF1 (Hooked, l-30mm, l/d-60), SF2 (Straight, l-6mm, l/d-37.5) indicates types of steel fibers. The fresh concrete properties are shown in Table 2.13.

Table 2.12: Mixture proportions (Sahmaran and Yaman, 2007)

Mix ID	Water	PC	Fly Ash	LP	FA	CA	SF1	SF2	SP	VMA
Control-PC	250	500	0	70	905	539	0	0	5.5	6.25
Control-Flysh	230	250	250	70	888	529	0	0	5.5	6.25
FA-SF1	226	250	250	70	889	530	60	0	5.5	6.25
FA-SF1&SF2)	205	250	250	70	925	550	30	30	5.5	6.25
FA-SF2	205	250	250	70	924	549	0	60	5.5	6.25

Table 2.13: Fresh concrete properties (Sahmaran and Yaman, 2007)

Mix ID	W/P	Fiber Ratio	Dmm	T_{500} (sec)	V-Funnel (sec)
Control-PC	0.44	0	560	2.9	4.3
Control-FA	0.40	0	690	<2	2.4
FA-SF1	0.40	42	660	<2	2.8
FA-SF1&SF2	0.36	35	630	<2	4
FA-SF2	0.36	29	700	<2	2.7

It is concluded from the test results that the slump flow diameter of all mixes were in range 560-700 mm .The V-funnel flow time were in range of 2.4-2.7 sec. Therefore, all concrete mixes were considered as SCC. In all mixes there was not segregation of aggregates near the edge of spread out concrete as observed from slump flow.

Steel fibers also affected the fresh properties of concrete mixtures.SF1 did not affect the water requirement of mix for same workability. However SF2 type fiber having small diameter reduced the amount of water required for workable SCC mix.

Akcay and Tasdemir (2012) studied five concrete SCC mixtures containing cement, silica fume, aggregate and water which were kept same. The nominal content of cement was 700 kg/m^3.The range of high range water reducer admixture was 3.8% by weight of cement for all concrete mixtures. The mixture proportion was Cement: Silica Fume: Water: Natural Sand: Crushed Stone: Coarse Aggregate in ratio 1:0.15:0.22:0.61:0.52:0.93. Three different steel fibers were added with and without hooked ends. Concrete mixtures were designated as REF (Plain SCC), C0.75N (concrete with 0.5%HSS + 0.25%NSH), C0.75H (concrete with 0.5%HSS + 0.25%HSH), C1.5N (concrete with 1% HSS + 0.5%NSH), C1.5H (concrete with 1%HSS + 0.5%HSH)

Where,

HSS denotes High strength straight steel fiber having length- 6mm, d-0.15mm and l/d-40

NSH denotes Normal strength hooked end steel fiber having length-30mm, d-0.55, l/d-55

HSH denotes High strength hooked end steel fibers having length-30mm, d-0.55, l/d-55

The fresh concrete properties are shown in Figure 2.1. It is observed that with the addition of steel fibers in SCC flow time has increased. The main influencing factor on flow ability is geometry of fibers. Flow rate is decreased with increasing fiber content. Flow test results are found in limits set by EFNARC (2005) specifications.

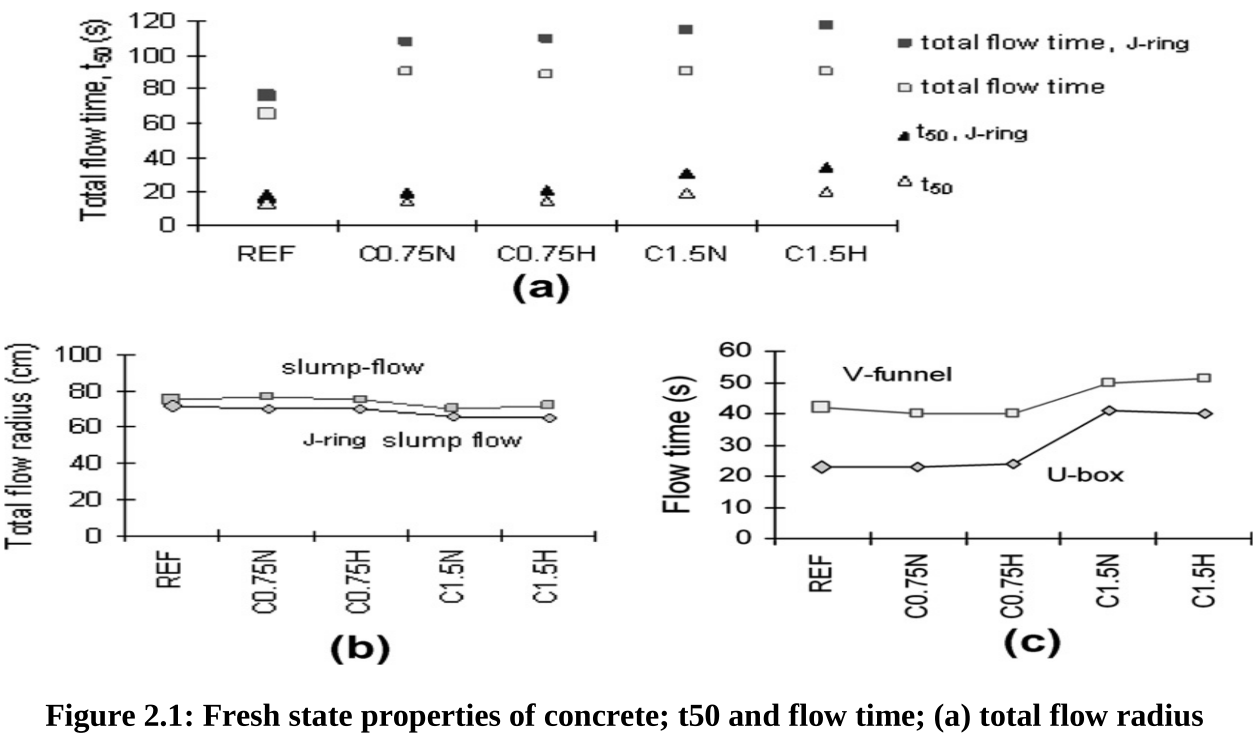

Figure 2.1: Fresh state properties of concrete; t50 and flow time; (a) total flow radius results of slump flow and J-ring test (b); and flow time results of V- funnel and U- box test (c) (Akcay and Tasdemir, 2012)

Khaloo et al. (2014) studied the SCC with various volume fractions of 0.5, 1, 1.5 and 2%.Ten mix designs were prepared ,two of which were plain and without any fiber while others had fibers. The abbreviation MS-SCC-PX stands for medium strength self compacting concrete and X is steel fiber volume fraction in percentage and HS-SCC-PX stands for the high strength self compacting concrete with steel fiber volume fraction in percentage. Hooked steel fibers of length 20.6, diameter 0.5 mm and aspect ratio 20 are incorporated in the SCC mixes. The mix proportions and characteristics of SCC reference mixtures are given in the Table 2.14

Table 2.14: Mix proportions of SCC reference mixes (Khaloo et al., 2014)

Specimens	w/b	Cement (kg/m^3)	Silica Fume	Water	Filler	Sand	CA	SP	VMA	Mortar Vol.(l/m^3)
MS-SCC	0.48	400	0	192	200	977	651	8	3.2	761
HS-SCC	0.38	500	50	209	200	861	574	7.5	4	795

The obtained results of fresh concrete revealed that slum flow time were less than 3.4 sec. According to EFNARC (2005), this time must be 2-5 sec. The time for two mixes was found less than 2 sec as shown in Figure 2.2. The slump flow diameter was in range of 640-800 as shown in Figure 2.3, satisfactory as per EFNARC (2005) specifications. The blocking ratios of all mixes in L-box test were in range of 0.65-0.96. The lowest ratio was 0.65 from MS-SCCF2 and the highest value is 0.96 for HS-SCC. The Blocking ratio of all mixes of MS-SCC was found less than 0.5, as shown in Figure 2.4. Also V- Funnel time observed was in range of 3 sec for HSC-SCC mix and 19.1 sec for SCC-F2 as shown in Figure 2.5.

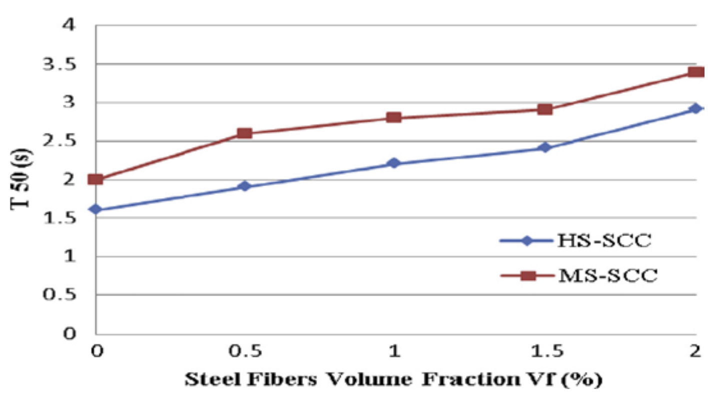

Figure 2.2: Slump flow time versus different percentages of fibers (Khaloo et al., 2014)

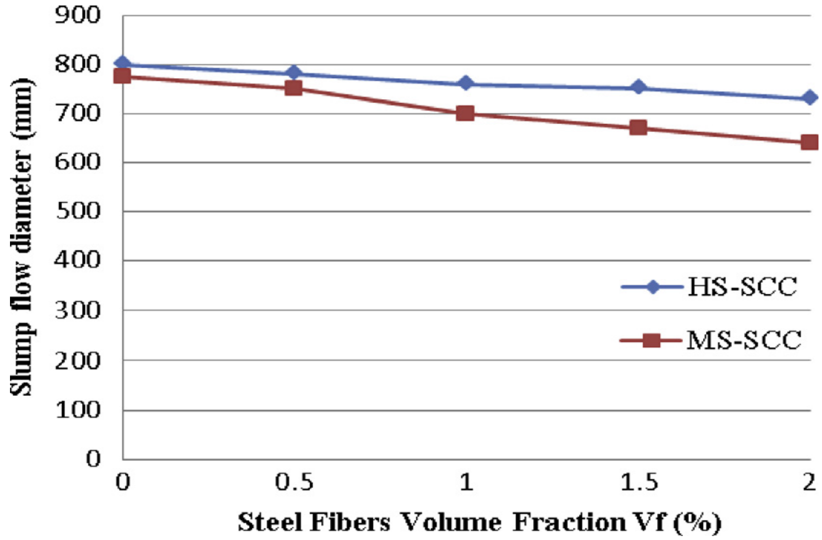

Figure 2.3: Slump flow diameter as function of fiber content (Khaloo et al., 2014)

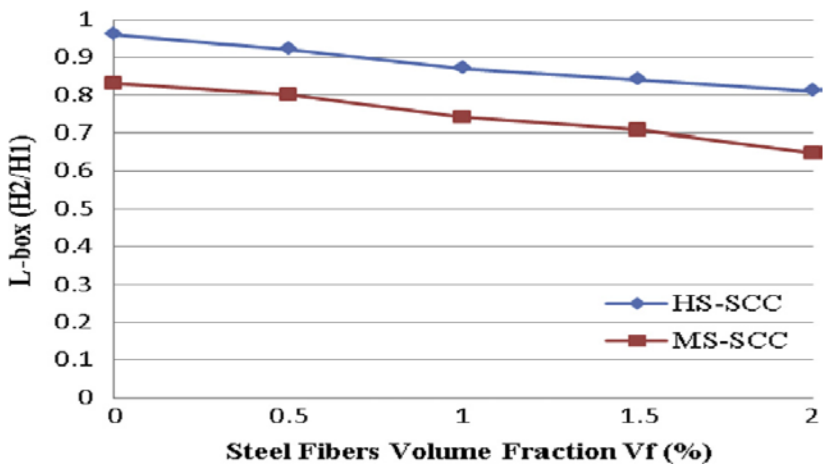

Figure 2.4: Variation of blocking ratio with increasing the percentages of steel fibers (Khaloo et al., 2014)

The rheological tests indicated that medium strength SCC reinforced with high vol. fraction especially 2% cannot be considered a acceptable mixture for heavenly reinforced sections due to difficulty of passing.

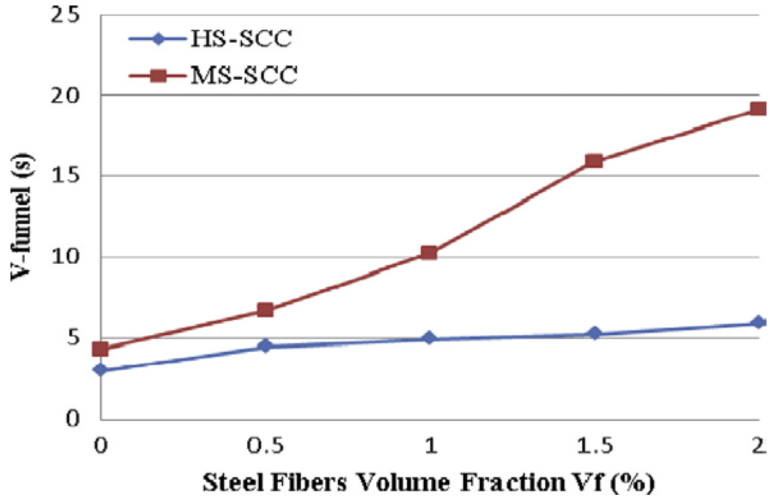

Figure 2.5: V-funnel time of different SCC mixtures (Khaloo et al., 2014)

Gencel et al. (2011) studied the fresh concrete properties .Five different mixes were prepared. Mix proportions in mass are shown in Table 2.15.

Table 2.15: Mix proportions in mass (kg/m^3) (Gencel et al., 2011)

Mix No.	Cement	Water	SP	Fly Ash	Fiber	Cst- I	NRS	Cst- II
1	400	160	6	120	0	523.6	433	788.3
2	400	160	6	120	15	521.9	431.7	785.8
3	400	160	6	120	30	520.4	430.4	783.4
4	400	160	6	120	45	518.7	429	781
5	400	160	6	120	60	517.1	427.7	778.5

Test on fresh concrete mix were done and test results of all five mixes are shown in Table 2.16

Table 2.16: Properties of fresh concrete (Gencel et al., 2011)

Mix No.	Slump Flow		V- Funnel (sec)	J- Ring (mm)	
	D (mm)	T_{500} (sec)		H1	H2
1	769	4.1	14.1	12	12.6
2	692	4.3	16.4	11.7	12
3	645	4.6	18.6	11.2	11.8
4	603	4.5	19.3	10.7	11.4
5	582	4.7	20.7	10.1	10.8

Slump flow time - All five mixes exhibited satisfactory results in ENFARC range of SCC i.e. 550-800 mm which is an indication of good deformability. Slump flow decreases with the addition and increase in percentage of fiber content.

V- funnel test - All five mixes of SCCs show flow time value in range of EFNARC i.e. 14- 20 sec. V- funnel flow time and T_{500} measurement of slump flow values are increasing with the addition and percentage of fiber content in the mixtures.

J- Ring test - All SCC mixes exhibit differences in heights of concrete inside and outside of ring, approximately 115 mm on an average. The steel fibers with hooked ends cause blocking of particles during flow.

2.2.2 Hardened concrete properties

2.2.2.1 Compressive strength

Khaloo et al. (2014) studied the compressive strength of medium strength and high strength SCC mixes with steel fibers of different volume fractions. The mix proportion of reference mixes are shown above in Table 2.14. The cylindrical specimens of sizes 150 x 300 mm were casted, cured in water and tested at ages 7, 28 and 91 days. The compressive strength test results at ages 7, 28 and 91 days of ten mixes are shown in Table 2.17.

Table 2.17: Compressive strength of various SCC mixes (Khaloo et al., 2014)

Specimens	**Compressive Strength (MPa)**		
	7 days	**28 days**	**91 days**
MS-SCC	29.4	39.7	47.3
MS-SCC-F0.5	26.4	38	46.3
MS-SCC-F1.0	24.2	35.1	43.2
MS-SCC-F1.5	23.2	33.4	40.3
MS-SCC-F2.0	22.4	32.9	40.2
HS-SCC	47.4	59.5	66.3
HS-SCC-F0.5	46	59.3	65.4
HS-SCC-F1.0	42.2	58.2	61.8
HS-SCC-F1.5	42.1	57.0	60.5
HS-SCC-F2.0	40.4	55.2	59.1

It was observed from test results that compressive strength decreases by increasing the percentage of steel fibers. Strength reduction might be due to decrease of workability of concrete which in turn causes reduction in compaction levels of vibrated concrete.

For Medium strength SCCs, at different ages, addition of fibers volume fractions from 0.5 to 2.0% causes compressive strength to decrease 4.3, 11.6, 14.6 and 18.6% respectively for 28 days specimens with respect to plain concrete (MS-SCC).

For High Strength SCCs, compressive strength decreases by adding more fiber volume fractions from 0.5 to 2.0%. The decrease in compressive strength of 28 days specimens is 0.7, 2.2, 4.2 and 7.5% respectively with respect to plain SCC specimens (HS-SCC).

The decrease in compressive strength for HS-SCC specimens are less than MS-SCC specimens and it may be due to HS-SCC specimens are workable than MS-SCC specimens.

The compressive strength increases with age yet the rate of this increase descends when age of specimen ascends.

Oliveira et al. (2013) studied compressive strength of 6 cubic specimens at age of 28 days. The composition and 28 days compressive strength of concrete mixtures are shown in Table 2.18.

Table 2.18: Characteristics of SFRSCC mixtures solutions (Oliveira et al., 2013)

Mixture	Proportion by weight (C:FA:Sand:Coarse aggregate)	w/b	Vol. Fiber (%)	SP/b (%)	Compressive strength (MPa)
A	1 : 0.15 : 1.78 : 1.72	0.40	0.0	2.0	27.0
B	1 : 0.15 : 2.00 : 1.50	0.40	0.5	2.5	27.0
C	1 : 0.30 : 2.06 : 1.44	0.40	1.0	2.5	25.5
D	1 : 0.50 : 2.15 : 1.35	0.40	1.5	2.5	26.5
E	1 : 0.15 : 2.00 : 1.50	0.40	0.5	2.0	24.9
F	1 : 0.30 : 2.06 : 1.44	0.38	1.0	2.0	26.5
G	1 : 0.50 : 2.25 : 1.25	0.35	1.5	2.0	29.0
H	1 : 0.15 : 2.10 : 1.40	0.39	1.0	2.5	20.0
I	1 : 0.15 : 2.25 : 1.26	0.38	1.0	3.0	21.0
J	1 : 0.30 : 2.76 : 1.74	0.69	1.0	2.0	17.0
L	1 : 0.30 : 3.46 : 2.03	0.69	1.0	2.84	14.0

Figure 2.6 shows compressive strength achieved by samples at 28 days.

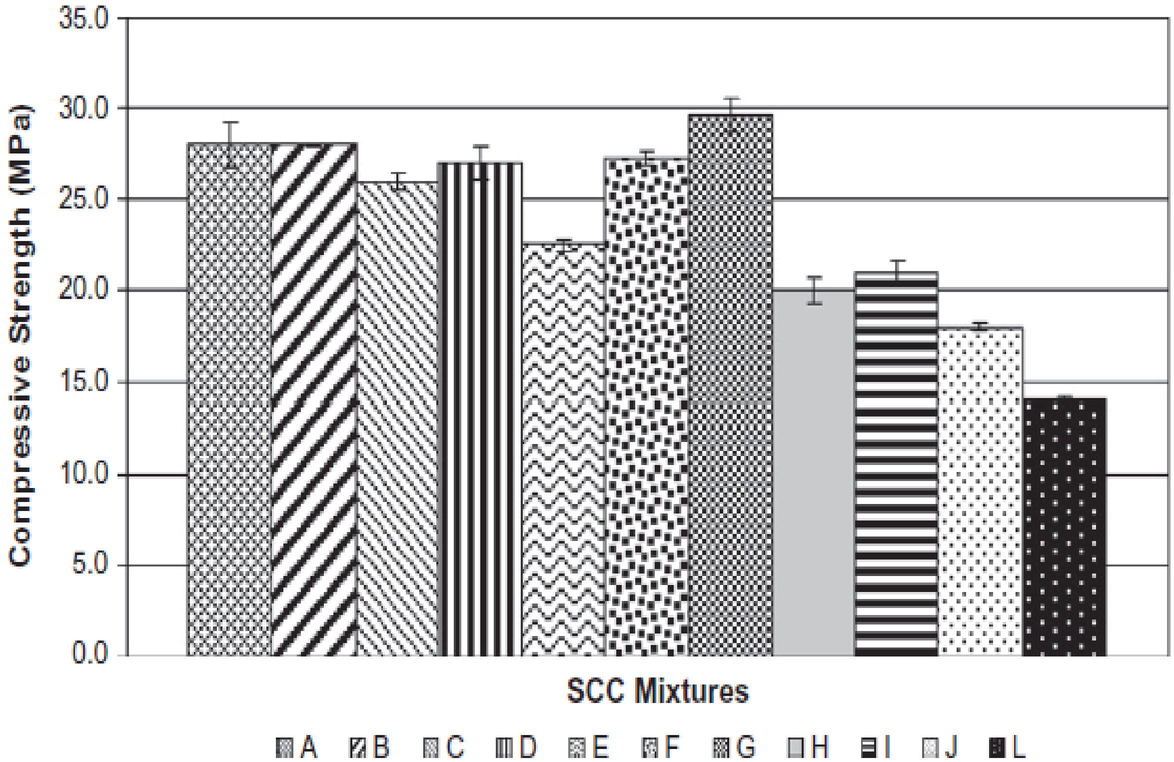

Figure 2.6: Results of SFRSCC compressive strength (Oliveira et al., 2013)

The results confirm that the steel fiber volume does not influence significantly the SFRSCC compressive strength. This fact is observed in mixture A to D where total aggregate and w/b was kept constant.

For normal steel reinforced concrete it is known that increasing volume and size of fibers did not offer a substantial improvement in compressive strength due to the fact that a fiber addition may lead to increased porosity.

Aydin (2007) studied the compressive strength by preparing ten SCC mixes with the incorporation of steel fibers in ratio of 0.25 to 2.0% with the increment of 0.25% and compared the compressive strength test results achieved by plain SCC mixes and all other steel fibers reinforced SCC mixes. The mix proportions and 28 days compressive strength of 10 mixes are shown in Table 2.19.

Table 2.19: Mixture proportions in kg/m^3 (Aydin, 2007)

Mixture	Water	Cement	Steel fiber (%)	Carbon fiber (%)	SP	QP	Sand	CA	28 days compressive strength (MPa)
M1	290	500	0	2	10	100	900	750	15.64
M2	290	500	0.25	1.75	10	100	900	750	18.47
M3	290	500	0.5	1.5	10	100	900	750	24.21
M4	290	500	0.75	1.25	10	100	900	750	22.57
M5	290	500	1.0	1.0	10	100	900	750	39.25
M6	290	500	1.25	0.75	10	100	900	750	18.70
M7	290	500	1.5	0.5	10	100	900	750	25.89
M8	290	500	1.75	0.25	10	100	900	750	24.41
M9	290	500	2.0	0	10	100	900	750	44.44
M10	290	500	0	0	10	100	912	761	36.68

It is observed that an increase in compressive strength was observed as the steel fiber content was increased. The highest compressive strength is achieved by Mix 9, having 2% fiber content by volume.

The strength properties at different volume fractions are presented in Figure 2.7.

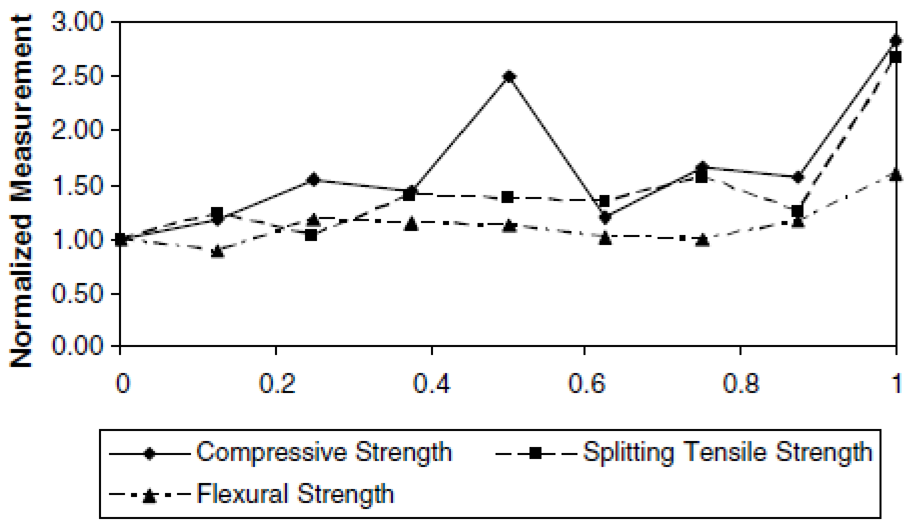

Figure 2.7: Strength properties of SFRSCC (Aydin, 2007)

Kamal et al. (2013) studied the compressive strength of SCC mixes containing steel fibers Different percentages of fibers were used in SCC mixes. The composition of all SCC mixes is shown in Table 2.6.

Figure 2.8 shows the compressive strength for the fiber SCC mixes at age 7 and 28 days.

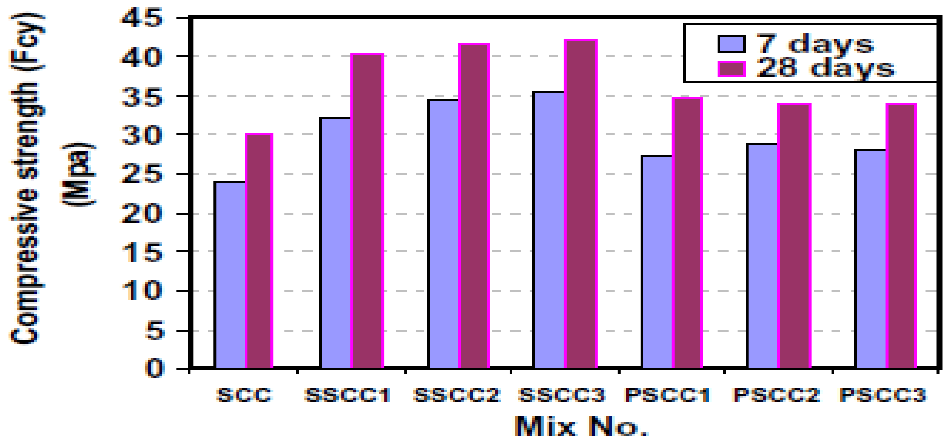

Figure 2.8: Compressive strength of different mixes (Kamal et al., 2013)

The compressive strength test results are shown in Table 2.20.

Table 2.20: Compressive strength of SCC and FRSCC mixes (Kamal et al., 2013)

Mix No.	Compressive Strength (MPa)	
	7 days	28 days
SCC(9)	24.0	30.3
SSCC1(10)	32.2	40.3
SSCC2(11)	34.5	41.5
SSCC3(12)	35.5	42.3

It is observed that compressive strength was found in range between 30.3 and 42.3 MPa at 28 days. An increase in compressive strength was observed in range between 33 to 40% for steel fiber SCC mixes compared with plain SCC.

Gencel et al. (2011) studied the compressive strength of five SCC mixes with steel fibers. The composition of SCC mixes is shown above in Table 2.17.

Figure 2.9 shows compressive strength test results of average of three specimens comparing with plain concrete, adding steel fibers at 15, 30, 45 and 60 kg/m^3 and found an increased the compressive strength by 3.2% and decreased by 3.4, 2.0 and 1.0% respectively. Addition of steel fibers converts the properties of brittle concrete to a ductile material, generally improving the compressive strength. The results of this study are not large increase.

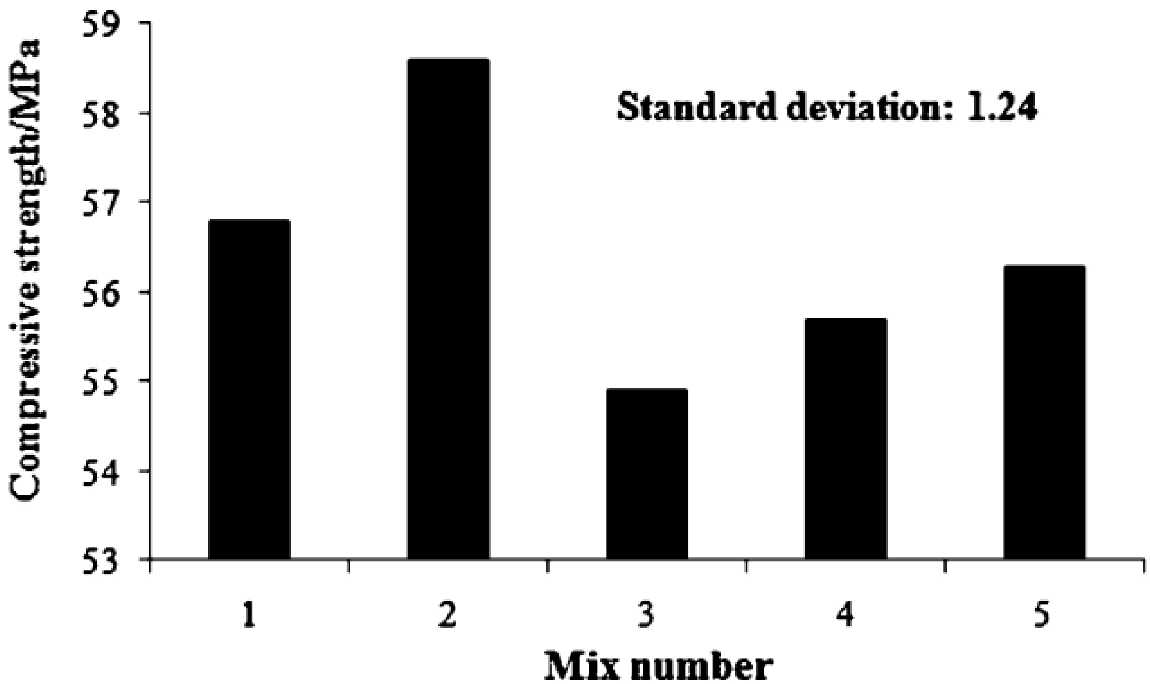

Figure 2.9: Compressive strength results (Gencel et al., 2011)

It is concluded that two factors are at play here. Thus, the addition of steel fibers provides reinforcement. Higher fiber concentration disrupts the homogeneity of concrete and causes decrease of strength. As still more steel fibers are included the reinforcement effect provides a gradual increase of strength.

EI-Dieb (2009) studied the compressive strength of five SCC mixes with the addition of steel fibers in different percentages by volume. The proportions of SCC mixes taken for study are shown in Table 2.25 The cubes of sizes 150 x 150 x 150 mm were casted and tested at ages 28 and 91 days .The test results are shown in Table 2.21.

Table 2.21: Variation of main mix composition (EI-Dieb, 2009)

Mix Composition	A	B	C	D	E
Total cementing materials (kg/m3)	775	775	900	900	900
Silica fume (%)	15	15	17.5	17.5	17.5
w/b	0.23	0.23	0.23	0.24	0.24
w/c	0.27	0.27	0.27	0.28	0.28
Fine Aggregate (%) –	45	60	60	50	100
- Coarse Sand(%) - Dune Sand (%)	76 24	100 0	70 30	70 30	70 30
Coarse Aggregate (%)	55	40	40	50	0
Compressive Strength(MPa) 28 days	88	92	110	95	85
Compressive Strength(MPa) 91 days	105	110	135	115	100

Figure 2.10 shows compressive strength with different volume fractions of steel fibers.

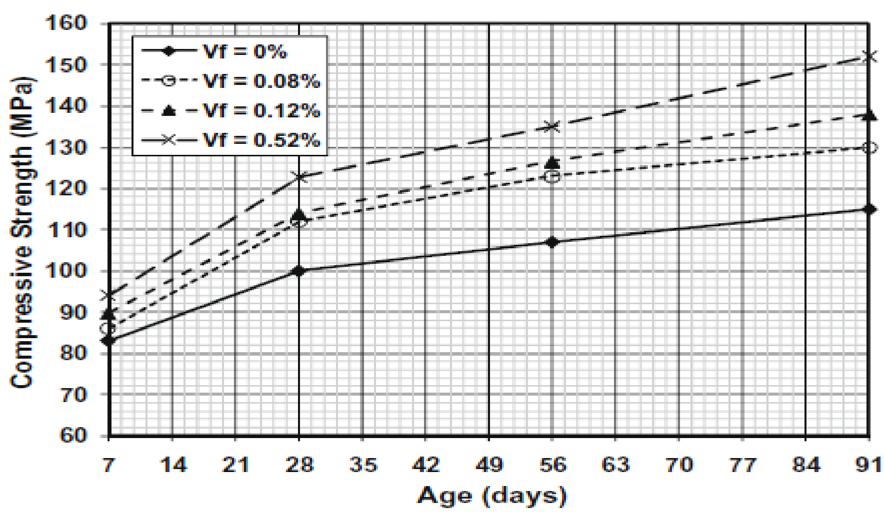

Figure 2.10: Compressive strength with age for different steel fiber volume fractions (EI-Dieb, 2009)

It is observed that Mix C yielded the highest compressive strength as UHSC which is greater than 100 MPa at age of 28 days.

Sahmaran and Yaman (2007) studied the compressive strength of hybrid steel fibers reinforced concrete and compared with control concrete mix design. The composition of SCC mixes taken for study is shown in Table 2.12. The compressive strength test results are shown in Table 2.22, which includes 28 and 56 days test results.

Table 2.22: Compressive strength test results (Sahmaran and Yaman, 2007)

Mixture ID	Compressive Strength (MPa)	
	28 days	56 days
Control-PC	40.7	41.7
Control-FA	23.3	28.6
FA-SF1	19.6	24.5
FA-SF1&SF2	22.8	26.1
FA-SF2	22.5	31.8

It was observed that reduction in compressive strength was 43% at 28 days and 31% at 56 days. This reduction could be attributed to pozzolanic activity of coarse fly ash. Fiber inclusion does not significantly affect the compressive strength. However, the volumetric ratio of SF2 type fiber of small dimensions increased the compressive strength as shown in Figure 2.11.

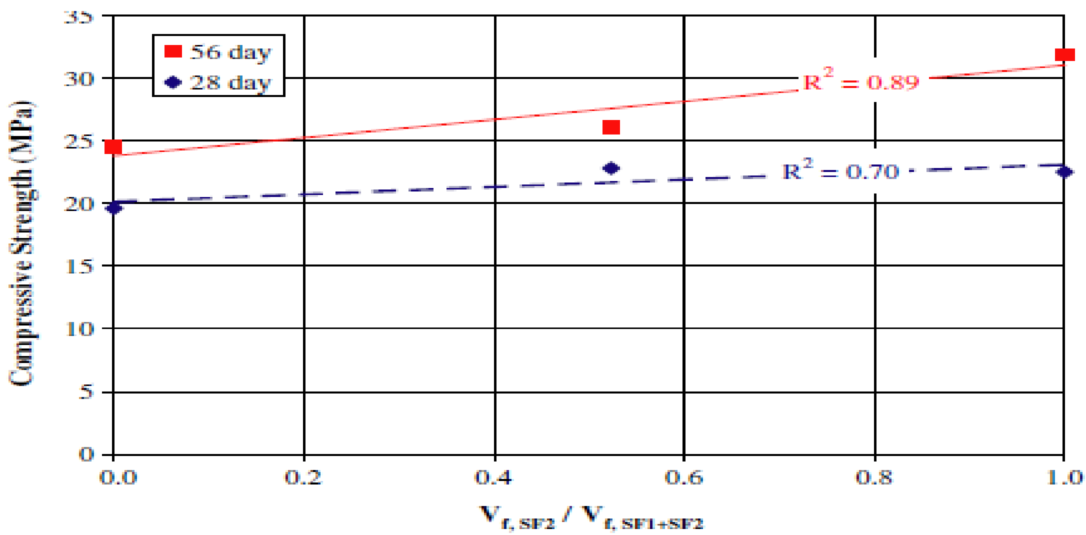

Figure 2.11: Effect of steel fibers on compressive strength (Sahmaran and Yaman, 2007)

2.2.2.2 Splitting tensile strength

Khaloo et al. (2014) studied the splitting tensile strength by casting the cylindrical specimens of sizes 150 x 300 mm, cured and tested at ages of 7, 28 and 91 days. The self compacting concrete proportions of medium and high strength, taken for study are shown in Table 2.14. The splitting tensile strength of specimens at ages of 7, 28 and 91 days are shown in Table 2.23.

Table 2.23: Splitting tensile strength of SCC mixes (Khaloo et al., 2014)

Specimens	**Splitting Tensile Strength (MPa)**		
	7 days	**28 days**	**91 days**
MS-SCC	2.20	3.37	3.46
MS-SCC-F0.5	2.26	3.40	3.59
MS-SCC-F1.0	2.43	3.71	3.80
MS-SCC-F1.5	2.48	3.97	4,01
MS-SCC-F2.0	2.75	4.33	4.43
HS-SCC	3.16	5.02	5.28
HS-SCC-F0.5	3.44	5.14	5.30
HS-SCC-F1.0	3.61	5.21	5.38
HS-SCC-F1.5	3.88	5.41	5.70
HS-SCC-F2.0	4.33	5.88	6.02

Splitting tensile strength increases by the addition of steel fibers. Adding more fiber vol. fractions causes more increase in splitting tensile strength. It was observed from the results that for medium strength class SCCs, with the addition of fiber vol. fractions 0.5, 1, 1.5 and 2.0% causes split tensile strength to increase 0.9, 10.1, 17.8 and 28.5% respectively with respect to plain specimens (MS-SCC) after 28 days of curing. For High Strength class SCCs, increasing the fiber vol. fractions from 0.5 to 2.0% causes splitting tensile strength to increase 1.2, 3.8, 7.8 and 17.1% respectively with respect to plain concrete (HS-SCC) after curing at 28 days.

Gencel et al. (2011) studied the compressive strength of five SCC mixes .The mix proportions taken for study is shown in Table 2.17. Six specimens of cylindrical molds of sizes 150 x 300 mm was casted and tested at 28 days. Figure 5 show increase in split tensile strength of all mixes. Figure 2.12 shows splitting tensile strength of mixes.

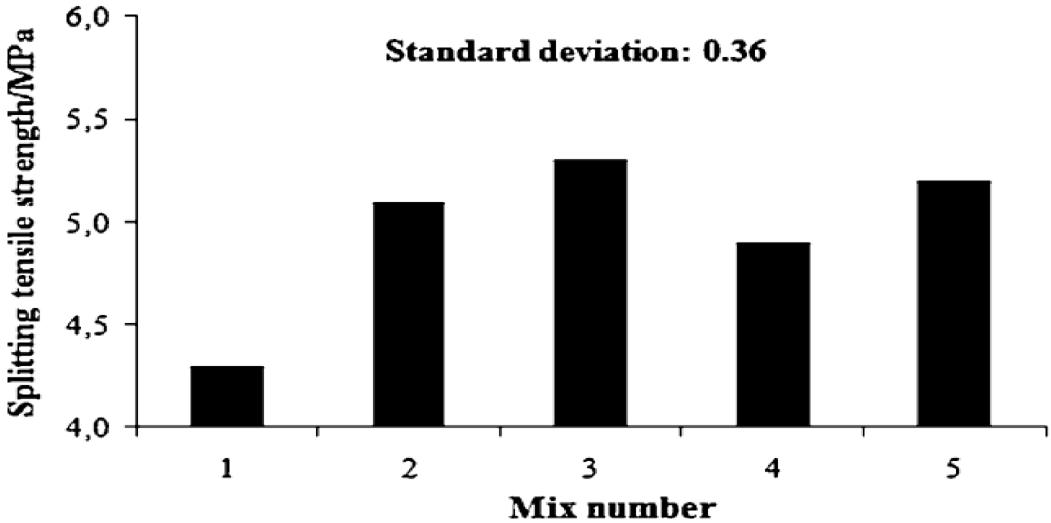

Figure 2.12: Splitting tensile strength results (Gencel et al., 2011)

It was concluded that when compared with plain concrete, splitting tensile strength of fiber-reinforced concrete increases by 18.6, 23.3, 14, and 21% for mixes 2, 3, 4 and 5 respectively. The increases are significant and the highest value is seen in Mix 3. The splitting tensile strength varies between 8.4 and 10% for 28 days compressive strength of concrete. There are numerous fibers bridging the micro cracks and preventing the expansion. When the tensile stress is transferred to fibers, the transfer can arrest the propagation of macro cracks and substantially improves the splitting tensile strength of concrete.

Sahamaran and Yaman (2007) studied the compressive strength of specimens prepared by SCC concrete mixes with the inclusion of steel fibers along with fly ash. The composition of concrete mixes taken for study, is shown in Table 2.12. The splitting tensile strength test results are shown in Table 2.24. Figure 2.13 shows effects of steel fibers on splitting tensile strength.

Table 2.24: Test results of splitting tensile strength (Sahamaran and Yaman, 2007)

Mix ID	Splitting Tensile Strength(MPa)	
	28 days	56 days
Control-PC	3.58	3.68
Control-FA	2.82	3.34
FA-SF1	3.10	3.69
FA-SF1&SF2	3.40	3.82
FA-SF2	3.08	3.23

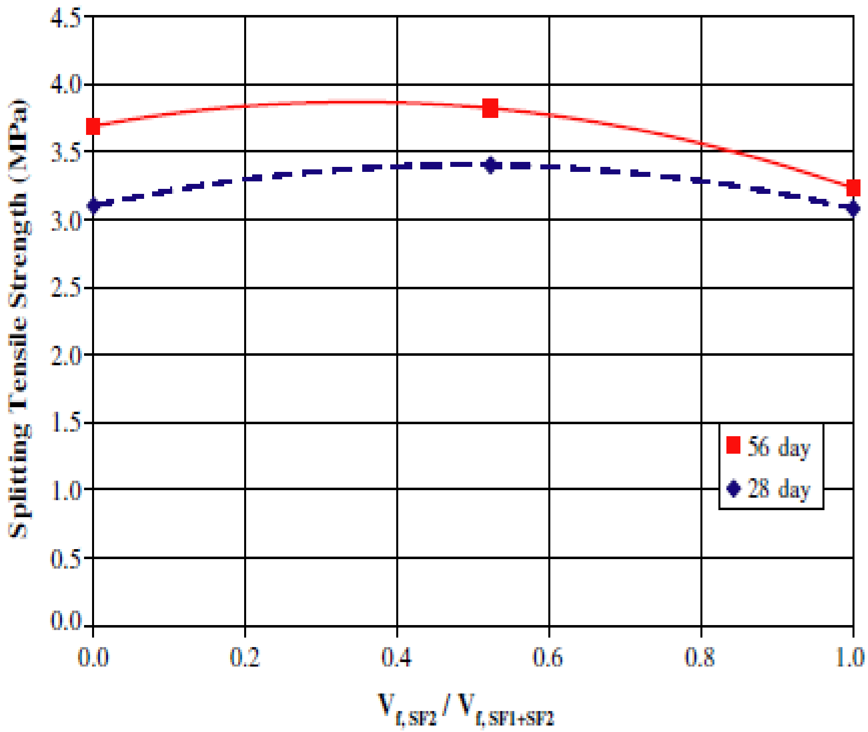

Figure 2.13: Effects of steel fibers on splitting tensile strength (Sahamaran and Yaman, 2007)

The most significant changes are seen in splitting tensile strength results. When coarse fly ash is substituted with Portland cement resulted in lower compressive and tensile strength at 28 and 56 days even though the w/p of mix was reduced. It is observed that there is reduction in splitting tensile strength as volume of SF2 type Fibers was increased. This reduction of splitting tensile strength is explained by loss of presence of longer SF1 fibers that also had hooked ends. Therefore, SF1 fibers were mainly responsible for increase in tensile strengths.

2.2.2.3 Flexural strength

Khaloo et al. (2014) prepared SCC with the addition of steel fibers in vol. fractions 0.5, 1.0and 1.5%.For the determination of flexural strength, beams of sizes 100 x 140 x 1200 mm were casted of each mixes and tested at 28 days. The composition of all the concrete mixes is shown in Table 2.14. The flexural strength and maximum bending load of beam at 28 days is shown in Table 2.25.

Table 2.25: Flexural strength at maximum bending load of beam at 28 days (Khaloo et al., 2014)

Specimens	Max. Load (KN)	Flexural Strength (MPa)
MS-SCC	4.81	4.41
MS-SCC-F0.5	5.00	4.59
MS-SCC-F1.0	5.32	4.88
MS-SCC-F1.5	5.43	5.00
MS-SCC-F2.0	7.02	6.44
HS-SCC	5.90	5.41
HS-SCC-F0.5	6.23	5.72
HS-SCC-F1.0	6.44	5.91
HS-SCC-F1.5	6.91	6.34
HS-SCC-F2.0	8.11	7.44

It was observed that by increasing the fiber volume fractions, the maximum bending load and flexural strength is increased. For medium strength SCC class, the addition of fiber vol. fractions from 0.5 to 2.0% causes the flexural strength increase by 4.1, 10.6, 13.4 and 46% respectively with respect to plain SCC specimens (MS-SCC) at 28 days.

Moreover, on addition of fiber volume fractions from 0.5 to 2.0% for high strength SCC class causes the flexural strength increase by 5.7, 9.2, 15.2 and 37.5% respectively with respect to plain SCC specimens (HS-SCC) at age of 28 days. Figure 2.14 shows load deflection diagram for plain concrete beams, while Figures 2.15 - 2.18, shows deflection diagrams for reinforced beams with 0.5, 1.0, 1.5, 2.0% steel fibers by volume fractions, respectively.

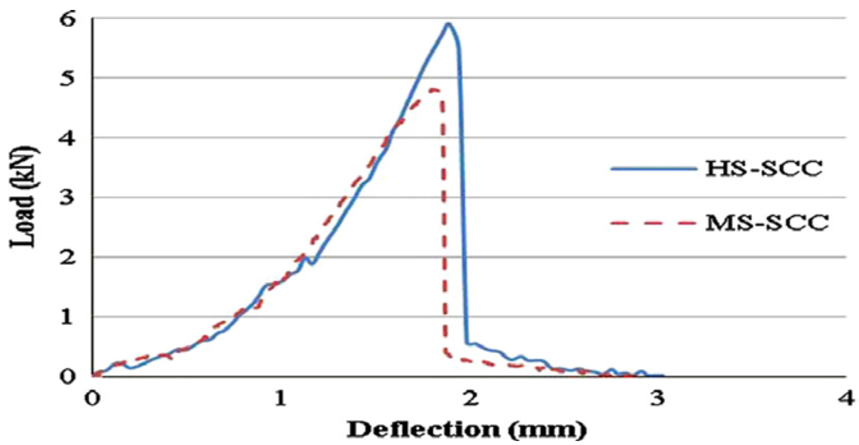

Figure 2.14: Load deflection diagram for plain concrete beams (Khaloo et al., 2014)

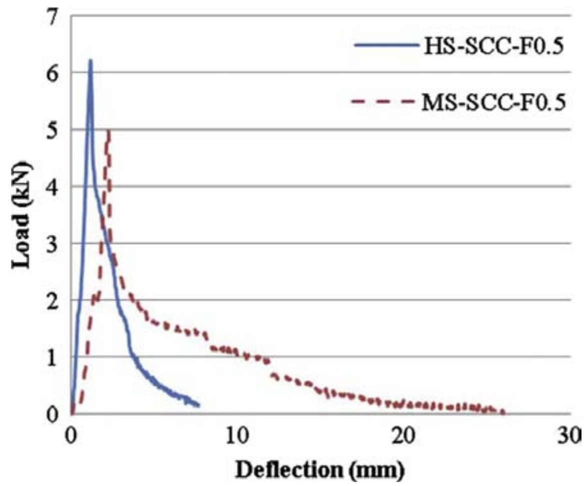

Figure 2.15: Load deflection diagram for reinforced beam with 0.5% steel fiber volume fraction (Khaloo et al., 2014)

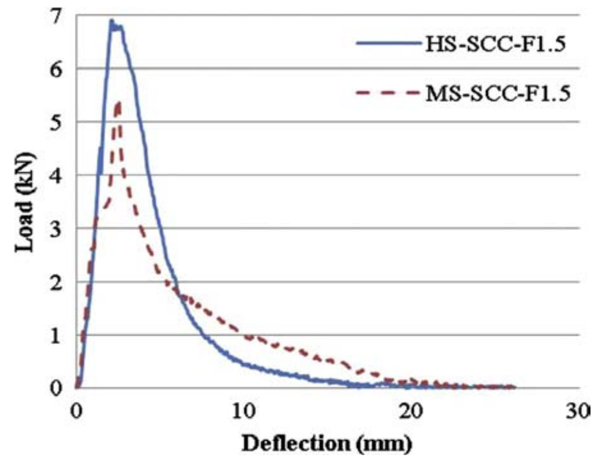

Figure 2.17: Load deflection diagram for reinforced beam with 1.5 % steel fiber volume fraction (Khaloo et al., 2014)

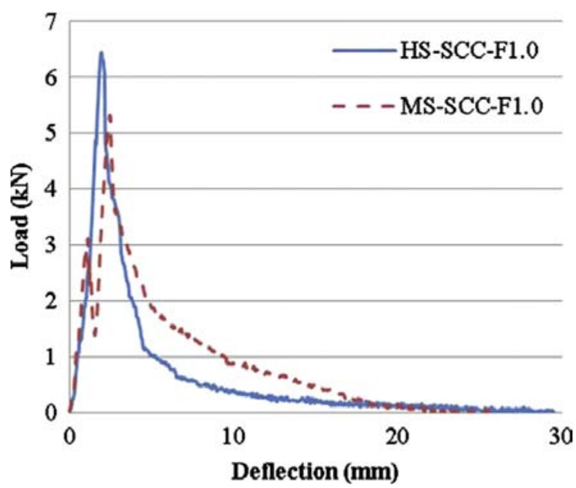

Figure 2.16: Load deflection diagram for reinforced beam with 1.0 % steel fiber volume fraction (Khaloo et al., 2014)

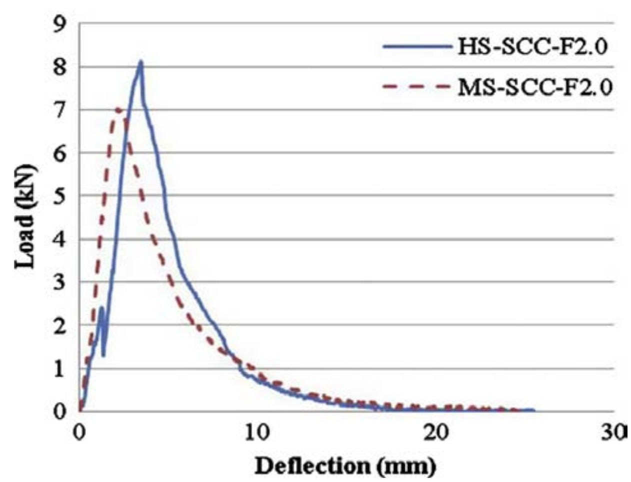

Figure 2.18: Load deflection diagram for reinforced beam with 2.0 % steel fiber volume fraction (Khaloo et al., 2014)

Aydin (2007) prepared ten SCC mixes with the addition of steel fibers. The concrete proportions taken for study are shown in Table 2.19. For flexural strength test of each mix, six samples of 70 x 70 x 280 mm prisms were casted and cured for 28 days and tested in accordance of ASTM C- 293. The flexural strength test results are shown in Table 2.26.

Table 2.26: Test results of flexural strength test of specimens (Aydin, 2007)

Mixture	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Flexural Strength (MPa)	6.1	5.37	7.22	6.98	6.89	6.18	6.07	7.05	9.75	6.4

It is observed that Mix 9 shows the highest flexural strength achieved at 28 days.

Gencel et al. (2011) compared the flexural strength of fiber reinforced SCC with Plain SCC .The results of flexural strength test are shown in Figure 2.19 shows flexural strength results of concretes and crack widths.

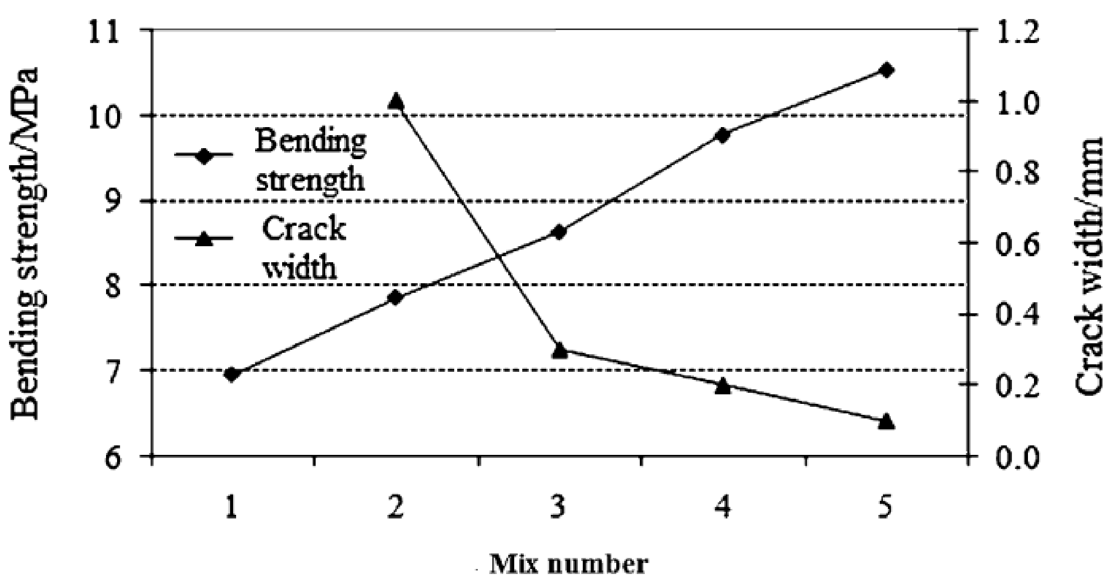

Figure 2.19: Flexural strength results of concretes and crack widths (Gencel et al., 2011)

It was observed that when compared with plain concrete, the flexural strength of fiber reinforced concrete is higher by 13.1, 24.2, 40.6 and 51.7% for mixes 2, 3, 4 and 5 respectively. The composition of concrete prepared for study, is shown in Table 2.17. The highest flexural strength is seen in Mix 5 which has the highest fiber content. Randomly distributed steel fibers control the cracks and stitch them. Therefore, the presence of fibers increases the load needed to fail the beam specimens.

2.2.2.4 Rapid chloride permeability test (RCPT)

Anastasiou et al. (2014) studied rapid chloride permeability test of nine SCC mixes prepared in series A-1, A-2, A-3, B-1, B-2, B-3, C-1, C-2, C-3. The proportions for all SCC mixes taken in the study are shown above in Table 2.12. The effect of ladle furnace slag (LFS) on chloride penetration resistance is shown in Figure 2.20.

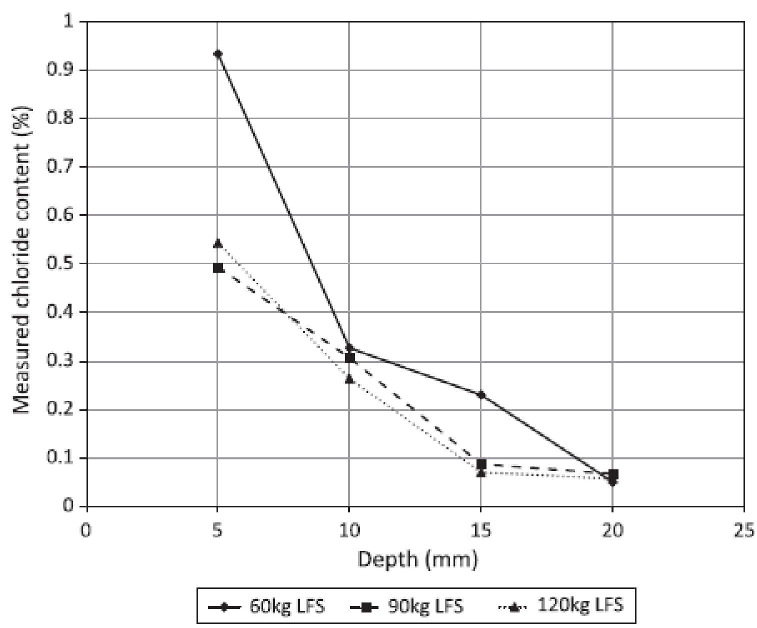

Figure 2.20: Effect of LFS on chloride penetration resistance (Anastasiou et al., 2014)

The use of increased amount of LFS, reduced the measured chloride contents considerably, as shown in Figure 2.20. This is due to chloride ion adsorption on cement matrix of SCC with LFS which act as pozzolonic material. The effect of steel fibers content on chloride ion penetration resistance is shown in Figure 2.21.

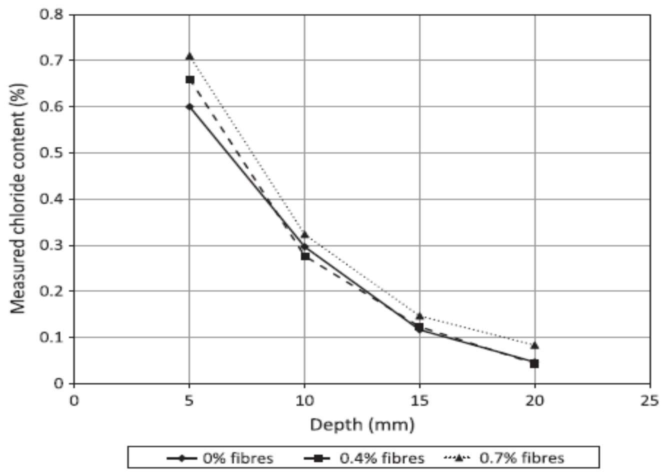

Figure 2.21: Effect of steel fiber content on chloride penetration resistance (Anastasiou et al., 2014)

It is concluded that steel fibers had minimal effect on chloride penetration resistance. The matrix with 0.7% fiber content showed only marginal increase in chloride contents measured.

EI- Dieb (2009) studied rapid chloride permeability test to evaluate the concrete durability against chloride attack, chloride induced corrosion and protection of reinforcement against corrosion. The mix proportions taken for the study are shown in Table 2.21.Figure 2.22 shows the total charge passing record in the RCPT.

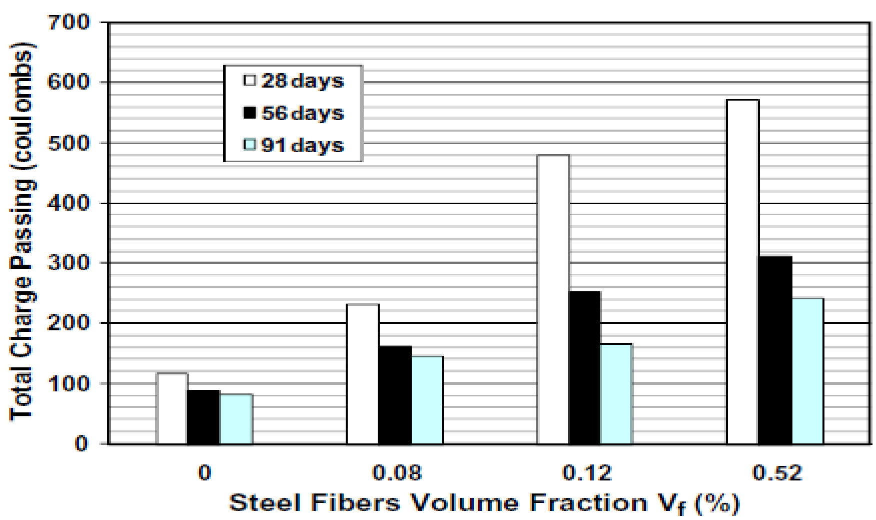

Figure 2.22: Total charge passing in RCPT for different steel fibers volume fractions (EI- Dieb, 2009)

The results indicate an increase in total charge passing as steel fibers volume fraction increases, this could be attributed to electrical conductivity of fibers. The total charge passing is reduced with age for all mixes. The recorded values of all chloride ion permeability indicate very low permeability, according to ASTM C 1202 classification.

The concrete electrical resistivity values support the findings in rapid chloride permeability test, as shown in Figure 2.23.

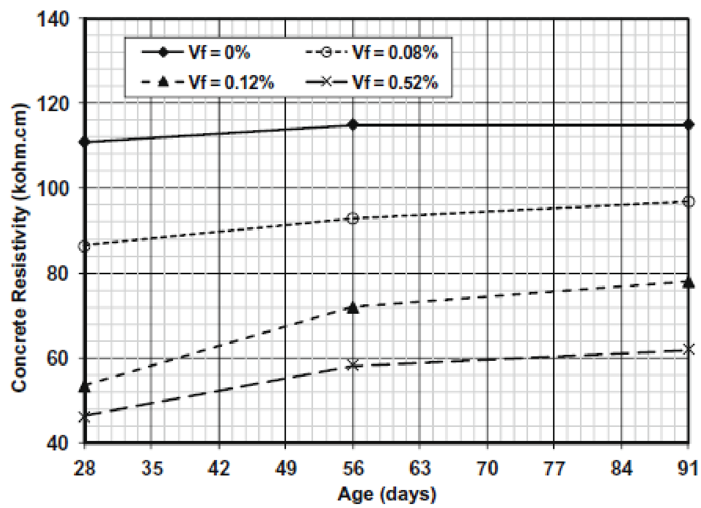

Figure 2.23: Effect of steel fiber volume fraction on concrete electrical resistivity (EI- Dieb, 2009)

The resistivity values of all mixes are found very high which indicates very good protection of steel reinforcement against corrosion.

2.2.2.5 Porosity

Corinaldesi and Moriconi (2004) studied the pore size distribution of SCC after 90 days of wet curing. For preparation of mixes, 0.4 w/c ratio was taken and kept constant and the SCC mixes proportions in kg/m^3 taken were water: cement: lime stone powder: natural sand: crushed aggregates: steel fibers: superplasticizer as 200: 500: 80: 1080: 420: 50: 9.4. Pore size of specimens was calculated by mercury intrusion technique. The test results are shown in Table 2.27.

Table 2.27: Pore size distribution of SCC after 90 days wet curing (Corinaldesi and Moriconi, 2004)

Pore Diameter (nm)	Porosity (% by Volume)
1 - 100	0.65
100 - 1000	8.84
1000 – 10,000	6.23
> 10,000	0.98
Total	16.70

EI- Dieb (2009) studied the durability properties by preparing four mixes with steel fibers in ratio of 0, 0.08, 0.12 and 0.52% by volume. It was concluded from the results obtained after testing of specimens at age of 28, 56 and 91 days that no much change is observed after inclusion of fibers. This could be due to the fact that water movement depends mainly on microstructure of cement paste. Since, the cement paste is almost same for all the mixes. The variations observed are within experimental sensitivity. The difference in sorptivity values ranges from 1 to 9%. From the results as shown in Table 2.28, it can be concluded that sorptivity values decreases with age.

Table 2.28: Sorptivity values for mixes with different steel fibers volume fractions (EI- Dieb, 2009)

Age (days)	Sorptivity ($mm/min^{0.5}$) for different volume fractions of steel fibers			
	0%	**0.08%**	**0.12%**	**0.52%**
28	0.0353	0.0365	0.0372	0.0385
56	0.0350	0.0360	0.0368	0.0377
91	0.0343	0.0346	0.0361	0.0375

2.2.2.6 Ultra sonic pulse velocity test (UPV)

Gencel et al. (2011) studied the ultra sonic pulse velocity test by preparing five SCC mixes with the incorporation of steel fibers at 15, 30, 45 and 60 kg/m^3. The SCC mix proportions taken for the study are shown in Table 2.15. The ultra sonic pulse velocity test was conducted as per ASTM C 597 after curing for 28 days.

Figure 2.24 shows pulse velocity of all concretes.

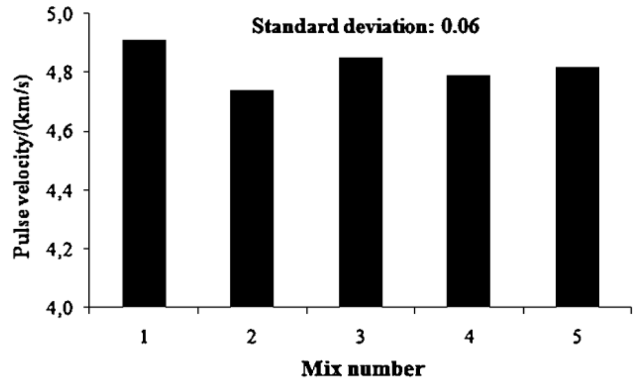

Figure 2.24: Pulse velocity in concretes (Gencel et al., 2011)

It was concluded that the maximum pulse velocity is observed in Mix 1 which is control mix, but the pulse velocity decreases with the incorporation of fibers in SCC mixes. The very small variations are observed seem to be an indication of uniformity of concrete matrix in all mixes.

Sahmaran and Yaman (2007) studied the ultra sonic pulse velocity test by preparing five SCC mixes by incorporating two types of steel fibers i.e. SF1 (l- 30mm, l/d- 55, hooked ends) and SF2 (l- 6mm, l/d- 37.5, straight). The mixture proportions taken for all SCC mixes are shown in Table 2.12. The test results of ultra sonic pulse velocity test conducted at ages 7, 14, 28 & 56 days with cubic specimens of sizes 150 x 150 x 150 mm, are shown in Table 2.30.

Table 2.29: Test results of ultra sonic pulse velocity test (Sahmaran and Yaman, 2007)

Mixture ID	**Ultra Sonic Pulse Velocity (m/s)**			
	7d	**14d**	**28d**	**56d**
Control- PC	4562	4570	4578	4609
Control-FA	4161	4260	4436	4564
FA- SF1	3963	4007	4157	4317
FA- SF1&SF2	3970	4100	4249	4383
FA- SF2	4142	4224	4359	4506

The results of ultra sonic pulse velocity test are shown in Figure 2.25.

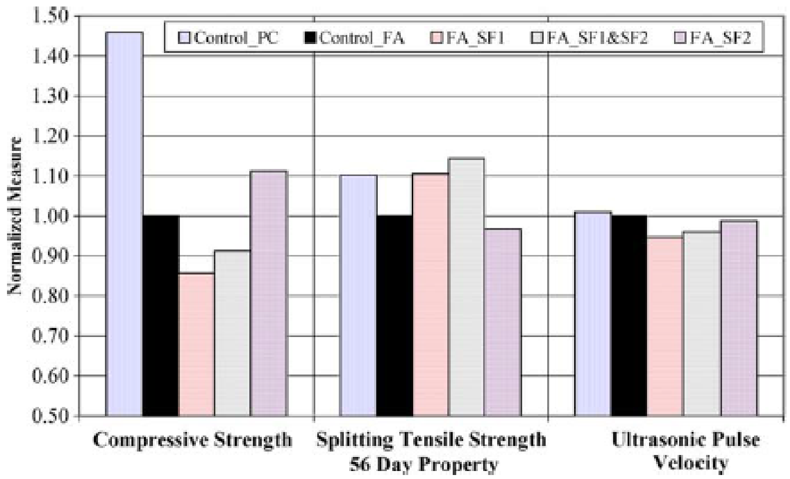

Figure 2.25: 56d hardened properties of concrete (compressive strength, Splitting tensile strength, ultra sonic pulse velocity (Sahamaran and Yaman, 2007)

The effect of high volume fly ash replacement and fiber inclusion on ultra sonic pulse velocity is found to be negligible. The UPV of SCC mixtures seemed to be unaffected by inclusion of steel fibers, as shown in Figure 2.26. It is clear from Figure 2.26 that as the hydration continued, UPVs increased for all the SCC mixtures.

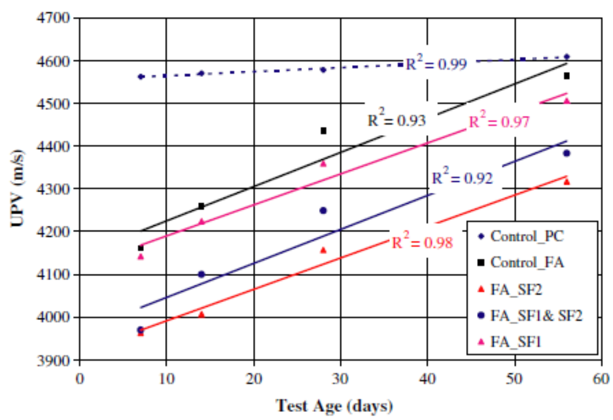

Figure 2.26: Ultra sonic pulse velocity of SCC mixtures (Sahmaran and Yaman, 2007)

The slope of curve was quite different for portland cement (PC) and fly ash (FA) mixtures. For control- PC mixture, the slope observed was much smaller as most of hydration was completed by 7 days. However, for mixtures with fly ash the hydration reactions continued after 7 days, indicating a higher slope as shown in Figure 2.26.

CHAPTER 3 EXPERIMENTAL PROGRAMMES

3.1 General

The chief aim of experimental program is to compare the properties of Self compacting concrete made with and without steel fibers, with the replacement of cement with fly ash as supplementary cementing material. The fundamental tests carried out on cement, aggregates and concrete samples are discussed in this chapter, followed by the short description about mix design and curing procedure adopted. At the end, the various tests conducted on the concrete specimens are discussed.

3.2 Materials Used

3.2.1 Cement

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel and crushed stone to create concrete. The cement and water form a paste that binds the other materials simultaneously as the concrete hardens. Grade 43 Ultra Tech cement was used for casting of cubes, cylinders and beams for all concrete mixes. The cement was of uniform colour grey with a light greenish shade and was free from any hard lumps. Summary of various tests conducted on cement conforming to IS: 8112-1989, is as under given below in Table 3.1.

Table 3.1: Basic tests conducted on Ordinary Portland cement (43 Grade)

Characteristics	Values Obtained	Standard Value (IS: 8112-1989)
Normal Consistency (%)	26%	-
Initial Setting Time (min.)	155	Not less than 30 min
Final Setting Time (min.)	220	Not be greater than 600 min
Fineness (m^2/kg)	283.4	Not less than 225 m^2/kg
Specific Gravity	3.15	-
Compressive Strength at 3 days	30.77 N/mm^2	27 N/mm^2
Compressive Strength at 7 days	42.8 N/mm^2	41 N/mm^2
Compressive Strength at 28days	46.7 N/mm^2	43 N/mm^2

The ordinary Portland cement contains two essential ingredients namely argillaceous and calcareous. In argillaceous materials, clay predominates and in calcareous materials, calcium carbonate predominates.

Composition of cement and fly ash as per Energy Dispersive Spectroscopy Analysis (EDXA; INCA x-act, Oxford Instrument, United Kingdom) is shown in Table 3.2. SEM analysis revealed the particle shape of ordinary portland cement is uneven, whereas fly ash is multilayered, micro porous and irregular as shown in Figure 3.1.

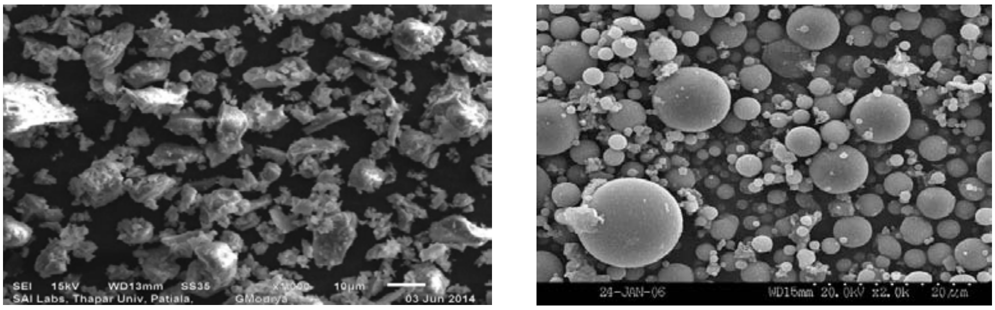

Figure 3.1: Microstructure by SEM analysis (A) OPC- 43 Grade (B) Fly ash- Class F

. **Table 3.2: Chemical composition limits of Ordinary Portland cement and Fly ash by EDX analysis**

Chemical Composition (% by mass)	Ordinary Portland Cement (43 Grade)	Fly ash (Class F)
Silicon Dioxide (SiO_2)	22.4	57.2
Aluminium Oxide (Al_2O_3)	5.87	25.4
Ferrous Oxide (FeO)	3.98	6.03
S + A + F	-	89
Magnesium Oxide (MgO)	0.92	2.42
Calcium Oxide (CaO)	55.83	1.14
Sodium Oxide (Na_2O)	0.76	0.42
Potassium Oxide (K_2O)	2.3	4.60
Sulphur Trioxide (SO_3)	2.86	0.16
L.O.I	0.6	1.12

*** S + A + F stands for SiO_2 + Al_2O_3 + FeO**

3.2.2 Fine aggregates

The material which passes through 4.74 mm sieve is termed as fine aggregate. The sand used for the experimental programme was locally procured and conformed to Indian Standard specifications IS: 383 (1970). The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm size and then was washed to take away the dust. Physical properties of fine aggregates used in the experimental work are tabulated in Table 3.3. The fine aggregates were sieved through a set of sieves to obtain sieve analysis and the same is accessible in Table 3.4. The fine aggregates belonged to grading zone III.

Table 3.3: Physical properties of fine aggregates

Characteristics	Values
Specific Gravity	2.582
Bulk Density	1.47 g/cc
Fineness Modulus	2.56
Water Absorption	1.712 %
Grading Zone (Based on %age passing through 0.60 mm sieve)	Zone – III

Table 3.4: Gradation of fine aggregates

Sieve Size (mm)	Weight of material retained (kg)	Percent material retained (%)	Percent material passed (%)	Cumulative percent material retained (%)
10	0	0	100	0
4.74	4.8	0.48	99.52	0.48
2.36	61	6.10	93.42	6.58
1.18	134	13.40	80.02	19.98
0.600	247	24.70	55.32	44.68
0.300	418	41.80	13.52	86.48
0.150	119	11.90	1.62	98.38
PAN	16.2	1.62		
SUM	1000		SUM	256.58
Total weight taken = 1000gm Fineness Modulus of Sand = 2.56				

3.2.3 Coarse aggregates

The material which is retained on IS Sieve no. 4.75mm is termed as coarse aggregate as per IS: 383 (1970). The crushed stone is generally used as coarse aggregate. The nature of work decides the maximum size of coarse aggregate. Locally accessible coarse aggregate having the maximum size of 12mm was used in our work. The aggregates were washed to remove dust and were dried to surface dry condition. The aggregates were tested as per IS: 2386 (1963) - Part 3. The results of various tests conducted on coarse aggregates are specified in Table 3.5 and Table 3.6 shows the sieve analysis results of coarse aggregates.

Table 3.5: Physical properties of coarse aggregates (12mm)

Characteristics	Value
Type	Crushed
Specific Gravity	2.676
Total Water Absorption	0.8%
Fineness Modulus	6.33

Table 3.6: Gradation of 12mm aggregates

Sieve size (mm)	Weight of material retained (kg)	Percent material retained (%)	Percent material passed (%)	Cumulative percent material retained (%)
20	0.091	3.03	96.97	3.03
10	0.889	29.63	67.34	32.66
4.75	1.96	65.33	2.01	97.99
2.36	0	0	0	100
1.18	0	0	0	100
0.600	0	0	0	100
0.300	0	0	0	100
0.150	0	0	0	100
PAN	0.06	2	-	-
			SUM	133.68
Total weight taken = 3kg Fineness Modulus of Coarse Aggregates = 6.33				

3.2.4 Water

Water is an important ingredient of concrete as it dynamically participates in the chemical reaction with cement. Since, it helps to form strength produce the cement gel, the quantity and quality of water is necessary to be looked into a very carefully. Potable water is generally considered satisfactory. In the present investigation, tap water is used both for mixing and curing purposes.

3.2.5 Supplementary cement materials

3.2.5.1 Fly Ash

Fly ash class F is obtained from Thermal Power Plant Bathinda, Punjab. The chemical composition of fly ash as per EDX analysis is shown in Table 3.1. Plate 3.1 shows the fly ash used in the study.

Plate 3.1: Fly ash used in the study

3.2.6 Admixture

Conplast SP 430, the super plasticizer complies with IS: 9103 (1979), BS: 5075 (Part 3) and ASTM - C – 494 Type ‘F’ as a high range water reducing admixture. Conplast SP 430 is based on Sulphonated Naphthalene Polymer and is supplied as brown liquid instantly dispersible in water and specially formulated to give high water reduction up to 25% without loss of workability, Specific gravity 1.22 to 1.225 at 30°C.

3.2.7 Steel fibers

Fibers made from mild steel drawn wire in compliance to IS: 280- 1976. The wires of diameter varying from 0.3 to 0.6 mm have been practically used in India. The efficiency of fiber distribution depends on the geometry of fibers, the fiber content, mixing technique, size and shape of aggregates, percentage of binder to enlarge the paste volume of SCC and mix proportions. Hooked Steel Fibers having 30 mm length, 0.5 mm diameter and aspect ratio – 50, are used in this study. Steel Fibers were obtained through Stewols India Pvt. Ltd. The percentages of steel fibers used in this study are 0.5, 1.0 and 1.5% by volume fractions correspondingly. Plate 3.2 shows the Hooked Steel Fibers used in the study. Table 3.7 shows properties of steel fibers used in the experiment.

Table 3.7: Properties of hooked steel fibers

Properties	Values
Length (mm)	30
Diameter (mm)	0.5
Aspect Ratio (l/d)	60
Tensile Strength (MPa)	1100
Specific Gravity	7

Plate 3.2: Hooked steel fibers used in the study

3.3 Mixture Proportioning

For the experiment, SCC mix is composed of Cement, Fly ash, coarse aggregates, fine aggregates, steel fibers, water and super plasticizer. The mix proportions of each mix are revealed in Table 3.8.

Table 3.8: Mix proportions of various SCC mixes in mass (kg/m^3)

Mix ID	Cement (kg)	Fly Ash (%)	Fly Ash (kg)	Steel Fiber (%)	Steel Fiber (kg)	Sand (kg)	CA (kg)	Water (kg)	W/B	SP (%)	SP (kg)
SCC1	450	10	50	0	0	910	590	205	0.41	1.2	6
SCC2	450	10	50	0.5	35	910	590	205	0.41	1.2	6
SCC3	450	10	50	1.0	70	910	590	205	0.41	1.2	6
SCC4	450	10	50	1.5	105	910	590	205	0.41	1.2	6

Where,

SCC1 = Self compacting concrete (control mix) with 10% fly ash as cement replacement and 0% steel fiber

SCC2 = Self compacting concrete with 10% fly ash as cement replacement and 0.5% steel fiber

SCC3 = Self compacting concrete with 10% fly ash as cement replacement and 1.0% steel fiber

SCC4 = Self compacting concrete with 10% fly ash as cement replacement and 1.5% steel fiber

CA = Coarse Aggregate

SP = Superplasticizer

3.4 Casting and Curing

For casting, the whole test specimen were cleaned and oiled properly. These were firmly tightened to correct dimensions before casting. Care was taken that there is no gaps left from where there is any possibility of leakage of slurry. Careful method was adopted in the batching, mixing and casting operations. The coarse aggregates and fine aggregates were weighed first with an accuracy of 0.5 g. The concrete mixture was prepared by hand mixing on a non-absorbing platform. On the non absorbing platform, the coarse and fine aggregates were mixed systematically, followed by cement, fly ash, steel fibers and (water + Superplasticizer). This procedure was adopted for all mixes in order to diminish the risk of a possible disparity between the homogeneity of each mix. Steel fibers were added after 30 seconds from starting of mixing procedure while the ingredients were dry and after 15 sec water with superlpasticizer started to be added steadily .Water was added carefully so that no water was lost throughout mixing. To this mixture, the cement was added. The total mixing time was 4 minute in order to make sure the uniformity. For each mix 24 samples were prepared, which consists of 12 cubes (150x150x150 mm) for 7 and 28 days, respectively for compressive strength and ultra sonic pulse velocity test, 12 cylinders (300x150 mm) for split tensile strength at 7 and 28 days, respectively. 12 cylinders (200x100 mm) for RCPT and Porosity test at 7 and 28 days, respectively and 12 beams for 7 and 28 days, respectively for flexural strength.

3.5 Tests Conducted

3.5.1. Fresh concrete tests (EFNARC, 2002)

SCC differs from conventional concrete in that its fresh properties are very important in determining whether or not it can be placed adequately. The various aspects of workability which control its Filling ability, its Passing ability and its Segregation resistance all need to be carefully controlled to make sure that its ability to be placed remains acceptable. A concrete mix can only be classified as Self-compacting Concrete if the necessities for all three characteristics are fulfilled.

- Filling Ability: Ability of to fill a formwork completely under its own weight.
- Passing Ability: Ability to overcome obstacles under its own weight without hindrance. Obstacles are e.g. reinforcement and small openings etc.
- Segregation Resistance: Homogeneous composition of concrete throughout and after the process of transport and placing.

It is important to appreciate that none of the test methods for SCC has yet been consistent, and the tests described are not yet perfected or definitive. The methods accessible here are descriptions rather than fully detailed procedures. They are mainly ad-hoc methods, which have been devised purposely for SCC.

3.5.1.1 Slump flow test

The slump flow test is done to review the horizontal flow of concrete in the lack of obstruction. It is most commonly used test and gives good assessment of filling ability. It can be used at sites. The test moreover indicates the resistance to segregation. The typical slump cone used is shown in Figure 3.2.

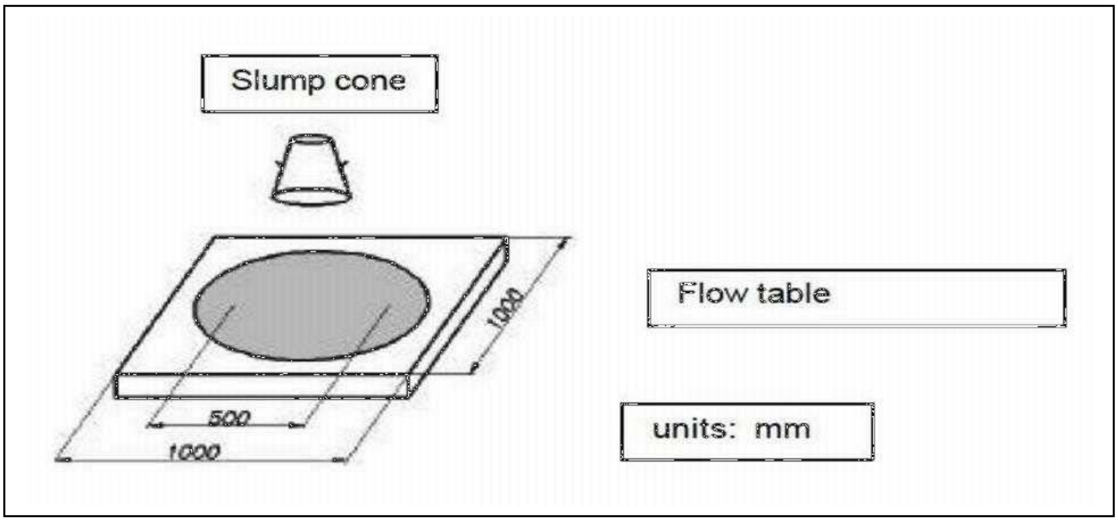

Figure 3.2: Schematic diagram for slump flow test (EFNARC, 2002)

Equipments

- The usual slump cone having base diameter of 200 mm, top diameter 100 mm and height 300 mm is used.
- A stiff base plate square in shape having at least 700 mm side. Concentric circles are marked around the centre point where the slump cone is placed. A firm circle is drawn at 500 mm diameter.
- A trowel
- Scoop
- Measuring tape
- Stop watch

Procedure

- About 6 L of concrete is desirable for the test.
- Base plate is set aside at a leveled ground surface. Keep the slump cone centrally on the base plate.

- Fill the cone with the scoop. Tamping is not at all mandatory in this case. Simply strike of the concrete level with the trowel. Remove the surplus concrete lying on base plate.
- Raise the cone firmly and permit the concrete to flow freely.
- Evaluate the final diameter of concrete in two perpendicular directions and compute the average of two diameters.
- This gives the slump flow in mm.
- Note that there is no water or cement paste or mortar without aggregates at the edges of the spread concrete.

Interpretation

The higher the flow value, greater is its ability to fill the formwork under its own weight. A value of at least 650 mm is required for SCC. In case if the aggregates are collected at centre and mortar at sides, segregation is practical.

3.5.1.2 T50 Slump flow test

Fundamental procedure for the test is same as in case of slump flow test. When the slump cone is lifted begins the stop watch and finds the time taken for the concrete to reach 500 mm mark. This time is called T50 time. This is a sign of rate of spread of concrete. A lesser time indicates greater flow ability. It is suggested that T50 time may be 2 to 5 sec. The study suggested that a time of 3-7 sec is acceptable for civil engineering applications, and 2-5 sec for housing applications.

3.5.1.3 V-funnel test

This test was developed in Japan and was used by Ozawa for the first time in 2001. The apparatus consists of a V-shaped funnel as shown in Figure 3.3

This test is essentially used to determine filling ability (flow ability) of concrete. The maximum size of aggregate used is 20 mm size. The funnel is filled with about 12 L of concrete. Time taken for the concrete to flow down is recorded. For T5min test the funnel is filled with concrete and left for 5 min to settle down. If the concrete shows segregation then the flow time will increase considerably.

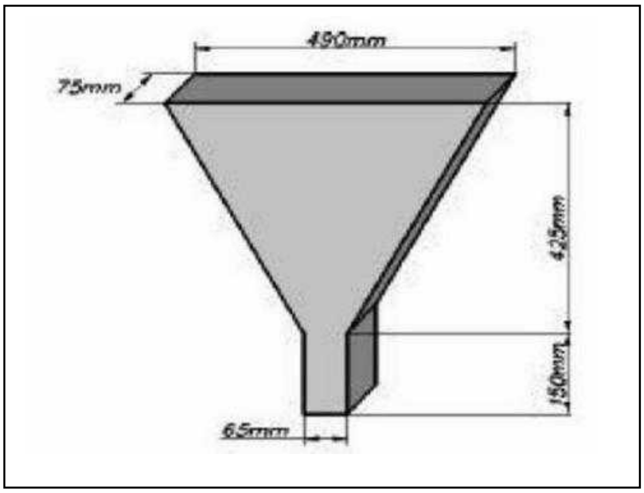

Figure 3.3: Typical V- funnel (EFNARC, 2002)

Equipments

- V-funnel
- Bucket – 12 L capacity
- Trowel
- Scoop
- Stopwatch

Procedure

- About 12 L of concrete is desired to perform the test, sampled normally.
- Lay down the V-funnel on firm ground.
- Moisten the inside surfaces of the funnel.
- Keep the trap door open to permit any surplus water to drain.
- Close the trap door and place a bucket beneath.
- Fill the equipment completely with concrete without compacting or tamping, simply strike off the concrete level with the top with the trowel.
- Unlock within 10 sec after filling the trap door and allow the concrete to flow out under gravity.
- Start the stopwatch when the trap door is opened, and record the time for the release to complete (the flow time). This is taken to be when light is seen from above through the funnel.
- The whole test has to be performed within 5 min.

Interpretation

This test measures the easiness of flow of the concrete; shorter flow times indicate greater flow ability. For SCC a flow time of 8-12 sec is considered appropriate. The inverted cone shape restricts flow, and lengthened flow times may give some indication of the susceptibility of the mix to blocking. After 5 min of settling, segregation of concrete will show a less uninterrupted flow with an increase in flow time.

3.5.1.4 L- box test

This test is based on a Japanese design for underwater concrete. The test assesses the flow of the concrete, and also the degree to which it is subject to blocking by reinforcement. Figure 3.4 shows the apparatus regarding L- box test.

The equipment consist of rectangular section box in the shape o fan 'L', with a vertical and horizontal section, separated by a changeable gate, in front of which vertical length of reinforcement bar is fitted. The vertical section is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. When the flow has blocked, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section. It indicates the slope of the concrete when at rest. This is a sign passing ability, or the degree to which the passage of concrete through the bars is restricted. The horizontal section of the box can be marked at 200 mm and 400 mm from the gate and the times taken to reach these points measured. These are documented as the T20 and T40 times and are an indication for the filling ability.

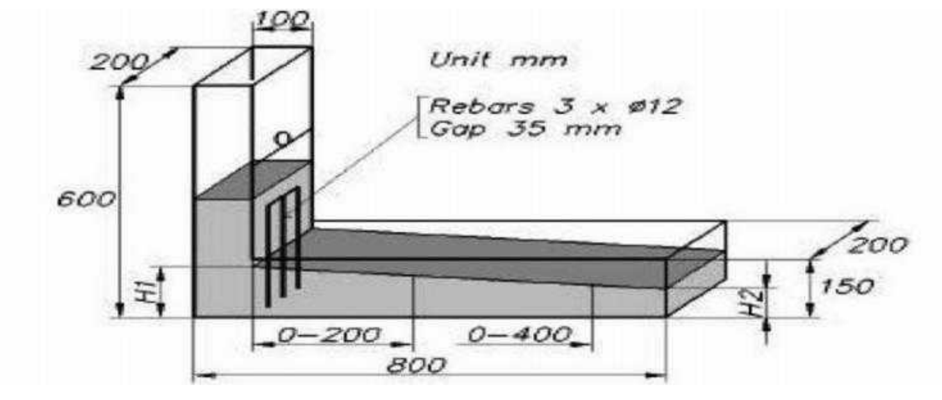

Figure 3.4: Schematic diagram for L- box (EFNARC, 2002)

Equipments

- L box of a still non absorbing material
- Trowel
- Scoop
- Stopwatch

Procedure

- About 14 L of concrete is desired to perform the test, sampled normally.
- Set the equipment level on firm ground, make sure that the sliding gate can open freely and then close it.
- Moisten the inside surfaces of the apparatus, take away any surplus water.
- Fill the vertical section of the apparatus with the concrete sample.
- Leave it to stand for 1 min.
- Raise the sliding gate and allow the concrete to flow out into the horizontal section. Simultaneously, start the stopwatch and record the times taken for the concrete to achieve the 200 and 400 mm marks.
- When the concrete stops flowing, the distances H1 and H2 are calculated.

Interpretation

If the concrete flows as freely as water, at rest it will be horizontal therefore H2/H will be equal to 1. Consequently nearer the test value, the blocking ratio is to unity, better the flow of concrete. Minimum tolerable value is 0.8. T20 and T401 time can give some indication of ease of flow. No suitable values have been suggested in this case. Clear blocking of coarse aggregate behind the reinforcing bars can be detected visually.

3.5.1.5 U-box test

This test was developed in Japan. This test was essentially used to measure the filling ability of self compacting concrete. This test was also called as "box - shaped" test. The equipment shown in Figure 3.5 consists of a vessel that is divided by a middle wall into two compartments i.e. Rand R1 2 An opening with a sliding gate is fitted between two chambers. 13 mm nominal diameter bars are installed at the gates with c/c distance of 50 mm. Clear spacing between the bars was 35 mm. Left hand chamber was filled with 20 L of concrete. The gate is then lifted and concrete is allowed to pass to another chamber. Heights of concrete in both chambers are considered.

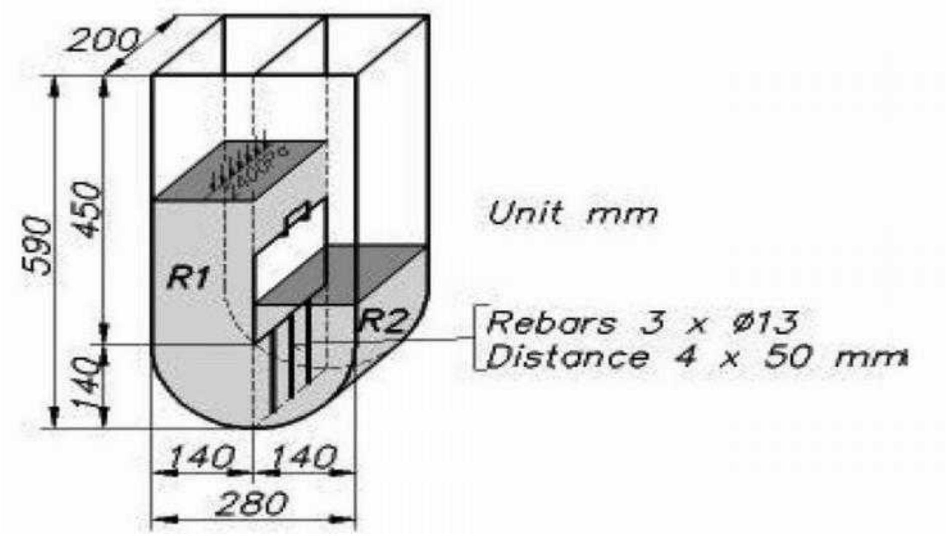

Figure 3.5: Schematic diagram for typical U-box (EFNARC, 2002)

Equipment

- U box of a stiff non absorbing material
- Trowel
- Scoop
- Stopwatch

Procedure

- About 20 L of concrete is desired to perform the test, sampled normally.
- Set the equipment level on firm ground, ensure that the sliding gate can open freely and then close it.
- Moisten the inside surfaces of the apparatus, take away any surplus water.
- Fill the one compartment of the apparatus with the concrete sample.
- Leave it to stand for 1 min.
- Raise the sliding gate and allow the concrete to flow out into the other compartment.
- After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled, in two places and compute the mean (H1). Measure also the height in the other compartment (H2)
- Calculate H1 - H2, the filling height.

- The complete test has to be performed within 5 min.

Interpretation

If concrete flows as freely as water, H2-H1=0. Nearer the test value, the filling height is to zero, better the flow and passing ability of concrete. The satisfactory value of filling height is 30 mm maximum.

3.5.2 Hardened concrete properties

3.5.2.1 Compressive strength IS: 516 (1959)

Objective: Determine the compressive strength of concrete specimen.

Apparatus: Testing machine as shown in Plate 3.3. The testing machine should be of adequate capacity for the tests and capable of applying the load at the particular rate. The permissible error shall not be greater than 2% of the maximum load. The testing machine shall be prepared with two steel bearing platens with hardened faces. One of the plates shall be fitted with a ball seating in the form the portion of the sphere, the centre of which coincides with the central point of the face of the platen. The other compression plates shall be plain rigid bearing block. The bearing faces of both plates shall be at least as larger as, and it should preferably be bigger than the normal size of the specimen to which the load is applied. The bearing surface of the plates, when new, shall not depart from a plane by more than 0.01 mm at any point, and they shall be maintained with a allowable variation limit of 0.02 mm, the movable portion of the spherical seated compression plates shall be held on the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted through small angles in any direction.

Procedure: Specimens stored in water shall be tested without delay on removal from the water and while they are still in the wet condition. Surface water and grit shall be wiped off the specimens and any projecting find detached specimens when received dry shall be kept in water for 24 h before they are taken for testing. The dimensions of the specimens to the nearest 0.2 mm and their weight shall be noted before testing. Placing the specimen in the testing machine the bearing surface of the testing machine shall be wiped clean and any loose sand or other material removed from the surface of the specimen, which are to be in contact with the compression platens. In the case of cubes, the specimen shall be placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom. The axis of the specimen shall be cautiously aligned with the centre of thrust of the spherically seated platen. No packing shall be used among the faces of the test specimen and steel platen of the testing machine. As the spherically seated block is brought to bear on the specimen, the movable portion shall be rotated quietly by hand so that uniform seating may be obtained. The load shall be applied without shock and enlarged continuously at a rate of approximately 140 kg/cm/min. until the resistance of the specimen to the increasing load breaks down and any remarkable features in the type of failure shall be noted.

Calculation: the measured compressive strength of the specimen shall be calculated by dividing the maximum load applied to the specimen during the test by the cross sectional area, considered from the mean dimensions of the section and shall be articulated to the nearest kg/cm. Average of three values shall be taken as the envoy of the batch provided the individual variation is not more than ±15 percent of the average. Otherwise repeat tests shall be made. A correction factor according to the height/diameter ratio of specimen after capping shall be obtained from the curve shown in Figure.1 of IS: 516-1959.

Plate 3.3: Compression testing machine used for study.

The product of this correction factor and the calculated compressive strength shall be known as the corrected compressive strength this being the comparable strength of a cylinder having a height/diameter ratio of two. The equivalent cube strength of the concrete shall be determined by multiplying the corrected cylinder by 5/4.

3.5.2.2 Splitting tensile strength test

Apparatus: Compression Testing Machine as shown in Plate 3.4.

Materials 150 x 300 mm moist cured concrete cylinders

Procedure:

1. Sketch diametric lines on all end of the specimen so that they are in the same axial plane.
2. Centre one of the plywood strips next to the centre of the lower bearing block.
3. Place the specimen on the plywood strip and align so that the lines marked on the ends are vertical and centered over the plywood strip.
4. Position the second plywood strip and the bearing bar so that they are end-to-end on the cylinder, centered on the formerly marked lines on the ends.
5. Apply the load constantly until failure occurs The load shall be applied without shock and increased constantly at a nominal rate within the range 1.2 N/ (mm2/min) to 2.4 N/ (mm/ min).
6. Record the maximum load at failure.
7. Determine the split tensile strength as follows:

Calculations:

The magnitude of tensile stress acting uniformly to the line of action of applied loading is given by formula

$$f_{ct} = \frac{2P}{\Pi l d}$$

Where,

f_{ct} = Split tensile strength in N/mm^2

P = maximum applied load to specimen in Newton

l= length of the specimen (in mm)

d = cross sectional dimension of the specimen (in mm)

Plate 3.4: Splitting tensile strength testing machine used in the study

3.5.2.3 Flexural strength test

Apparatus: Universal Testing Machine

Procedure:

Specimens of size 150 x150 x 700 mm are cured and tested on universal testing machine.

The bearing surfaces of the supporting and the loading rollers shall be wiped clean from the surface of the specimen where they are to make contact with the rollers..Then the specimens shall be placed in the machine in such a manner that load shall be applied to the upper most surface as cast in the mould along two lines spaced 20 or 13.3 cm apart. The axis of the specimens shall be carefully aligned with the axis of the loading device. No packing shall be used between the bearing surface of specimens and the rollers .The load shall be applied without shock and increasing continuously.

The beams were tested by placing them uniformly in the universal testing machine of capacity 1000 KN. This test was performed on universal testing machine (UTM) as shown in Plate 3.5. The test is carried out at the loading rate of 70 KN/min.

The magnitude of flexural stress acting uniformly to the line of action of applied loading is given by formula

$$f_b = \frac{p \times l}{b \times d^2}$$

f_b = flexural strength in N/mm^2

p = maximum applied load to specimen in Newton

l = length of the span on which the specimen was supported

b = measured width of the specimen

d = measured depth of the specimen at point failure

Plate 3.5: Flexural strength testing machine used in the study

3.5.2.4 Rapid chloride permeability test (RCPT) ASTM C 1202 (2010)

The RCPT was originally developed for the Federal Highway Administration (FHWA) by the Portland Cement Association (Whiting, 1981) to provide a rapid test method that correlated well with ponding tests, such as AASHTO T 259. Ponding tests are considered to be the best method of determining the chloride permeability of concrete, but they take 90 days or more to complete, making them impractical for project quality assurance testing. Two very similar standards (AASHTO T 277 and ASTM C 1202) describe the rapid chloride permeability test. The tests are performed using 2 in. (51 mm) long, 3.75 in. (95 mm) diameter cylindrical specimens cut from cores obtained with a diamond-dressed coring After the curved surface of a test specimen is coated with epoxy, the specimen is vacuum saturated with water Rapid Chloride Permeability Tests and then soaked for 18 h. As shown in Plate 3.6 and Figure 3.6. The specimen is then placed in the testing apparatus where one end of the specimen is exposed to a solution containing 3% sodium chloride (NaCl) and the other end is exposed to a solution containing 0.3 N sodium hydroxide (NaOH). To increase the rate of chloride penetration into the specimen thus speeding up the test, a constant 60 V potential is applied across the specimen. The current across the specimen is measured at least every 30 min during the 6 h test. In theory, as the chlorides penetrate deeper into the concrete, the pore solution becomes more conductive and the current readings increase. In concretes with high conductivity values, on the other hand, these effects are small relative to changes in conductivity due to temperature rise.

Plate 3.6: Vacuum desiccators bowl

To reduce the effects of heating and resultant changes in conductivity over the 6 h period of the test, it's been suggested that earlier values be adjusted to obtain an equivalent 6 h coulomb value. The total charge passing through the specimen (in Coulombs) is found by calculating the total area under the plot of time versus current. Therefore, higher coulomb values at the completion of the test indicate higher permeability.

Plate 3.7: Rapid chloride permeability test set up (ASTM C 1202).

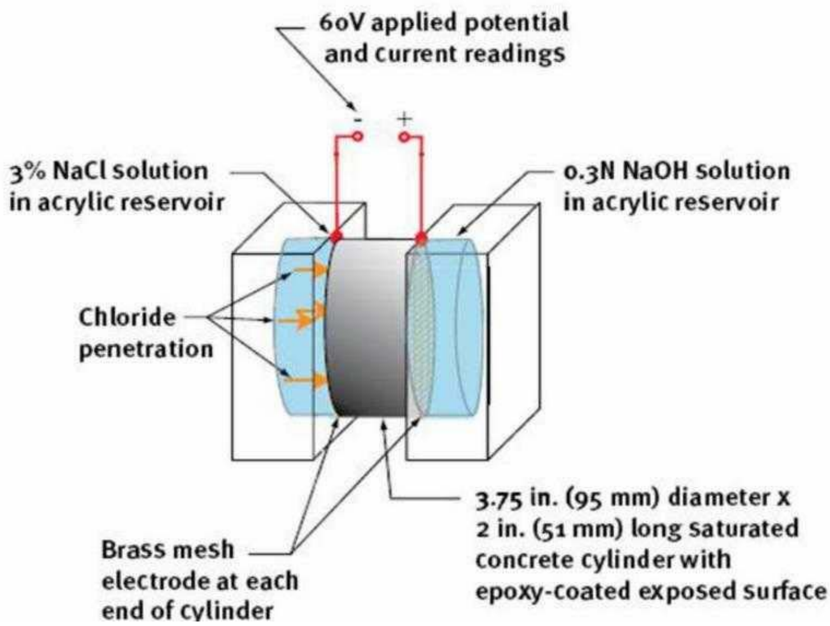

Figure 3.6: Schematic representation of rapid chloride permeability test setup

The rapid chloride permeability test does not, however, directly measure the depth or rate of chloride penetration. This makes it difficult to directly correlate results from the test with a desired service life and has led to a significant amount of debate about the proper use and applicability of the test. It should also be noted that, in quality control and acceptance testing applications, ASTM C 1202 (2010) recommends the use of the qualitative terms shown in the right hand column of Table 3.9 rather than the numerical results of the test.

Table 3.9: Chloride ion penetrability based on charge passed (ASTM 1202-2010)

Charge Passed (Coulombs)	Chloride Ion Penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

3.5.2.5 Porosity ASTM C 642 (2006)

Aim **–** Determination of density, percentage absorption and percentage voids in hardened concrete.

Significance and Use:

This test method is useful in developing the data required for conversions between mass and volume for concrete. It can be used to determine conformance with specifications for concrete and to show differences from place to place within a mass of concrete.

Apparatus:

- Balance, sensitive to 0.025 % of the mass of the specimen.
- Container, suitable for immersing the specimen and suitable wire for suspending the specimen in water.

Test Specimen:

The sample shall consist of several individual portions of concrete, each to be tested separately. The individual portions may be pieces of cylinders, cores, or beam of any desired shape and size, except that the volume of each portion shall be not less than 350 cm^3 (or for normal weight concrete, approximately 800 g); and each portion shall be free from observable cracks, fissures, or shattered edges.

Procedure:

1. Oven-Dry Mass--Determine the mass of the portions, and dry in an oven at a temperature of 100 to 110 °C for not less than 24 h. After removing each specimen from the oven, allow it to cool in dry air (preferably in desiccators) to a temperature of 20 to 25 °C and determine the mass. If the specimen was comparatively dry when its mass was first determined, and the second mass closely agrees with the first, consider it dry. If the specimen was wet when its mass was first determined, place it in the oven for a second drying treatment of 24 h and again determine the mass. If the third value checks the second, consider the specimen dry. In case of any doubt, re dry the specimen for 24 h periods until check values of mass are obtained. If the difference between values obtained from two successive values of mass exceeds 0.5 % of the lesser value, return the specimens to the oven for an additional 24 h drying period, and repeat the procedure until the difference between any two successive values is less than 0.5 % of the lowest value obtained. Designate this last value A.

2. Saturated Mass after Immersion - Immerse the specimen, after final drying, cooling, and determination of mass, in water at approximately 21 ^oC for not less than 48 h and until two successive values of mass of the surface-dried sample at intervals of 24 h show an increase in mass of less than 0.5 % of the larger value. Surface-dry the specimen by removing surface moisture with a towel, and determine the mass. Designate the final surface-dry mass after immersion B.

Plate 3.8: Samples boiled in curing tank at maintained temperature

3. Saturated Mass after Boiling - Place the specimen, processed as described in 5.2, in a suitable receptacle, covered with tap water, and boil for 5 h. allow it to cool by natural loss of heat for not less than 14 h to a final temperature of 20 to 25 °C. Take away the surface moisture with a towel and determine the mass of the specimen. Designate the soaked, boiled, surface-dried mass C.

4. Immersed Apparent Mass - Suspend the specimen, after immersion and boiling, by a wire and conclude the apparent mass in water. Designate this apparent mass D.

Calculation:

By using the values for mass determined in agreement with the measures described in, make the following calculations:

1. Absorption after immersion, % = [[B-A]]/A]*100

2. Absorption after immersion and boiling, % = [[C-A]/A]*100

3. Bulk density, dry = [A/[C-D]] ρ =g1

Bulk density after immersion = [B/[C-D]] ρ

4. Bulk density after immersion and boiling = [C/[C-D]] ρ

5. Apparent density = [A/[A-D]] ρ = g2

6. Volume of permeable pore space or voids = [(g2-g1) / g2]*100

OR

[(C-A)/(C-D)]*100

Where:

A = mass of oven-dried sample in air, g

B = mass of surface-dry sample in air after immersion, g

C = mass of surface-dry sample in air after immersion and boiling, g

D = apparent mass of sample in water after immersion and boiling, g

g1 = bulk density, dry, mg/m3 and

g2 = apparent density, mg/m3

r = density of water = 1 mg/m3 = 1 g/cm3.

3.5.2.6 Ultra Sonic Pulse Velocity Test

Ultra sonic pulse velocity test was performed on 150 mm cubes in accordance with the standards (ASTM C 597, 2009) as exposed in Plate 3.9.

Apparatus:

The testing apparatus consists of a pulse generator, a pair of transducers (transmitter and receiver), an amplifier, a time measuring circuit, a time display unit and connecting cables.

Procedure:

Determination of calibration correction- Check the accuracy of the transmit time measuring against the calibration device and the calibration device constant is the calibration correction which must be included in the determination of transit time. Check the calibration over a range of transit times that includes the transit times anticipated.

Determination of zero correction- Apply zero time correction to the measured transit times. The zero correction is equal to travel time between the transmitting and the receiving transducers with the zero thickness of concrete between the two. Measure it directly by pressing the two transducers together using a coupling agent and applying the same pressure used in the actual measurement and measure the transit time. With digital display units, it may be preferable to make zero adjustment by coupling the two transducers to opposite ends of a reference bar for which the transit time is accurately known.

Determination of transit time- Apply an appropriate coupling agent such as water, oil, petroleum, grease etc. to the transducers diaphragms, the testing surface or both to avoid entrapped air between the contact surfaces of concrete. Press the faces of the transducers and the surface of the concrete, assuring good contact between the two and measure the transit time. Measure the length of the shortest direct path between the centers of diaphragms. Pulse velocity was determined by the pulse time to length of the path as shown in the following equation.

$$V = l/t$$

Where,

V = Velocity (Km/sec)

l = length of path (Km)

t = time (sec)

Plate 3.9: Pulse Velocity Test

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 General:

In this chapter the parameters on concrete made with 10% replacement of cement with fly ash and with the addition of hooked steel fibers in different percentages are discussed. The parameters such as rheological properties of fresh concrete by tests like slump flow,T_{50CM} , V-funnel, L-box, U-box etc. and the mechanical properties of hardened concrete by tests like compressive strength, splitting tensile strength, flexural strength, rapid chloride permeability, porosity and ultra sonic pulse velocity are studied and comparison between different mixes are discussed.

Steel Fiber

The effects of addition of steel fibers in percentage by volume in SCC mix are basically discussed in this chapter. Steel fibers act as crack arrestors, restricts the development of cracks in concrete. Portland cement with fibers in concrete make a strong composite with superior crack resistance also improves ductility. The bond with concrete mixes of steel fibers is dependent on aspect ratio (l/d), length of fibers and volume fraction of steel fibers used. The addition of fibers into self-compacting concrete may take advantage of its high performance in the fresh state for uniformly dispersal within the matrix as well as many advantages like the improvement in the economic efficiency of the construction process, increased speed of construction, reduction or suitably focused rearrangement of labor resources, costs and energy consumption, better working environment, with reduced noise and health hazards, also the contribution toward the automation and reliability of quality control (Ferrara et al., 2007).

Fly ash

Fly ash is added in the mix to increase the quantity of filler and to decrease the quantity of cement content for the production of the workable SCC. Silica present in fly ash reacts with calcium hydroxide (CH) to form additional binder material called calcium silicate hydrate (C-S-H) similar to C-S-H produced by Portland cement. It acts as additional binder which produces

SCC with reduction in volume of large pores. The concrete mix is densified with pore size reduction. Also, shrinkage and permeability of hardened concrete are decreased due to filling of micro pores.

Concrete is brittle and weak in tension. Steel fibers are incorporated in the concrete mixes to improve these deficiencies. The addition of steel fibers improves the mechanical properties and ductility of SCC. However, the fibers greatly impair the workability of SCC because of their elongated shape and large surface area. The maximum amount of fibers needs to be determined by preparing different trial mixes having different percentages of steel fibers, in such a way to cause the least decrease in the workability, whilst maintaining good flowing and passing ability. In order to make the best use of steel fibers, they need to be homogeneously distributed in the mix without clustering.

Steel fibers and fly ash enhance the performance of self-compacting concrete, consisting of very fine powder. Studies proved that these materials improve the quality of the concrete both in fresh and hardened states. As the volume of the micro-filler materials increases, the distance between the large sizes aggregates also increases, reducing the internal friction of the concrete. As the blockage of the large aggregates is prevented, the flow and workability properties of the fresh concrete are improved. The developed volumetric water-to-powder ratio method enables the use of binding materials effectively and provides a tool for optimization, as well as new areas for research on the interaction between the microstructure and mechanical properties of the concrete (Sengul et al., 2006).

The concrete properties are improved with the combined addition of steel fibers and fly ash in fresh state i.e. deformability, passing ability, filling ability and segregation resistance as well as in hardened state i.e. mechanical and durability properties. The improvements in properties of SCC are because of enhancement in interfacial or bond strength of both steel fibers with concrete and pore- refinement by fly ash in Self compacting concrete.

4.2 Fresh Concrete Properties

The fresh concrete properties are assessed by flow ability, passing ability, consistency and segregation resistance of SCC containing different percentages of steel fibers. The fresh concrete properties of SCC are evaluated by slump flow test, $T_{50\ cm}$ (sec), V-funnel test, L-box test, U-box test respectively. It is known that using steel fibers within the concrete matrix will decrease the workability significantly.

Various mixes have been designed and tested for fresh concrete properties. SP content varied from 1-1.4% and w/b ratio was varied from 0.32-0.41.The optimum results were obtained by mix containing 10% fly ash replaced with cement, 1.2% SP and 0.41 w/b ratio. The results of fresh concrete properties of all SF SCC and are included in Table 4.1.

Table 4.1: Fresh concrete properties of mixes with and without steel fibers

Mix ID	Steel Fiber (%)	Slump Flow (mm)	V-Funnel (Sec)	L-Box (H2/H1)	U-Box (H1-H2)
SCC1	0	710	**7**	0.98	6
SCC2	0.5	680	8	0.9	19
SCC3	1	630	11	0.85	26
SCC4	1.5	570	12	0.8	29

In terms of slump flow, All SCC mixes exhibited satisfactory slum flow in range of 550-800 mm which is an indicator of good deformability. The effect of steel fiber content by volume (%) on Slump Flow is shown in Figure 4.1.

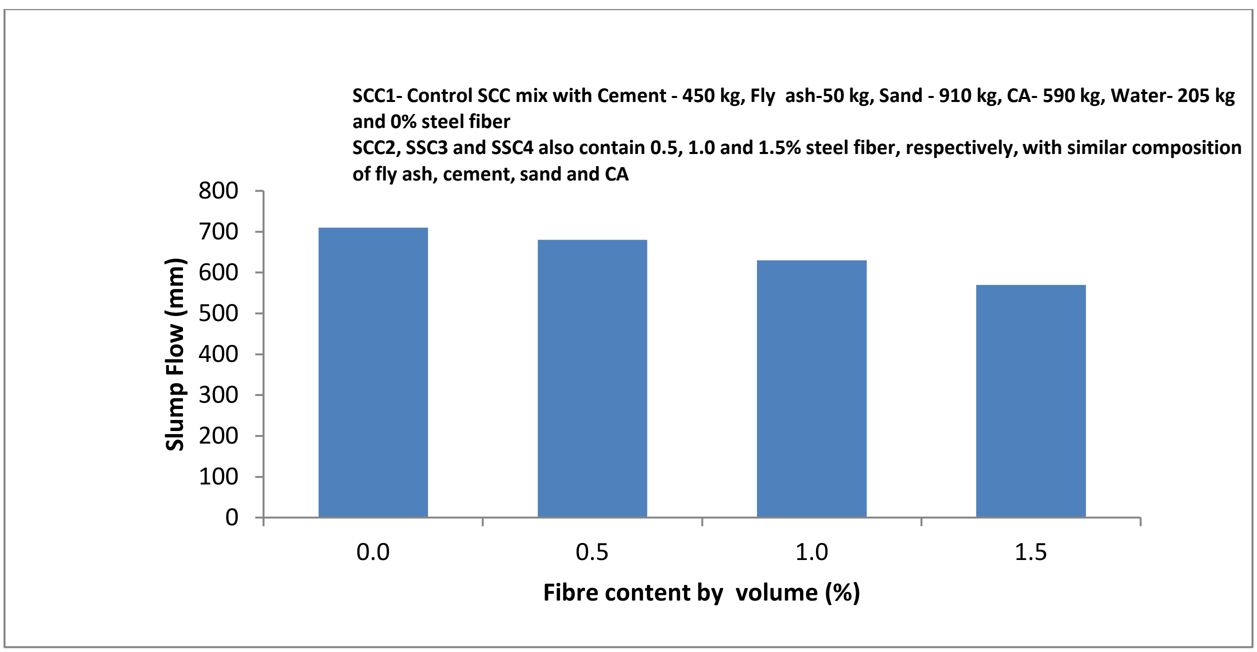

Figure 4.1: Effect of steel fiber content on slum flow test of SCC

As per EFNARC, time of V-funnel test ranges from 6-12 sec. is considered adequate for a SCC. The V-funnel time was found in range of 7-12 sec. V-funnel time increased by incorporating steel fibers in mixes as illustrated in Figure 4.2. Test results of this investigation indicated that all SCC mixes meet the requirements of allowable flow time.

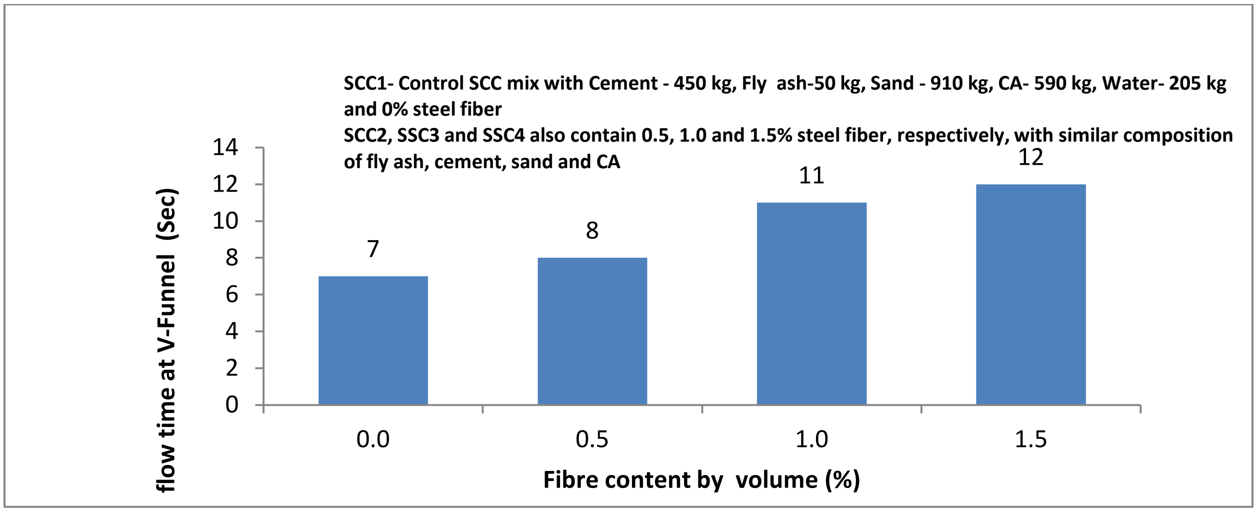

Figure 4.2: Effect of steel fiber content on flow time at V- funnel test of SCC

Increase in fiber content leads to increase the friction between fibers and aggregates and friction of fibers with each other which could extend the required time to empty the V- funnel. The L-box ratio (H2/H1) for mixes was found above 0.8 i.e. as per EFNARC range. The U- box difference in height of concrete in two compartments was in range of 5- 40 mm. The results show that Blocking ratio increased with increasing steel fibers, plotted in Figure 4.3.

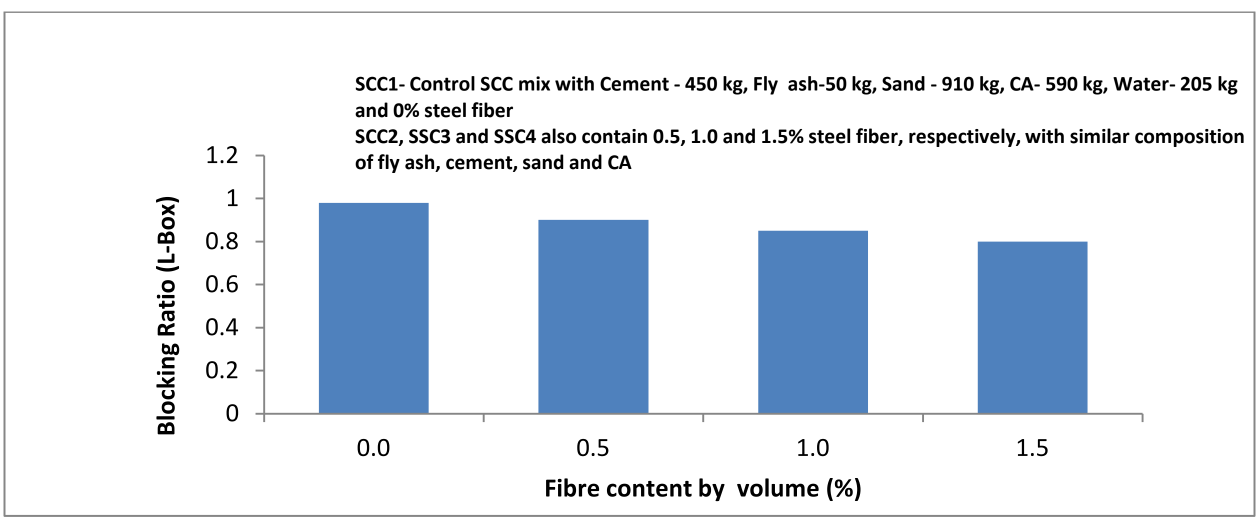

Figure 4.3: Effect of steel fiber content on blocking ratio (L- box) test of SCC

The U- box test results are plotted in Figure 4.4 with increase in steel fiber content.

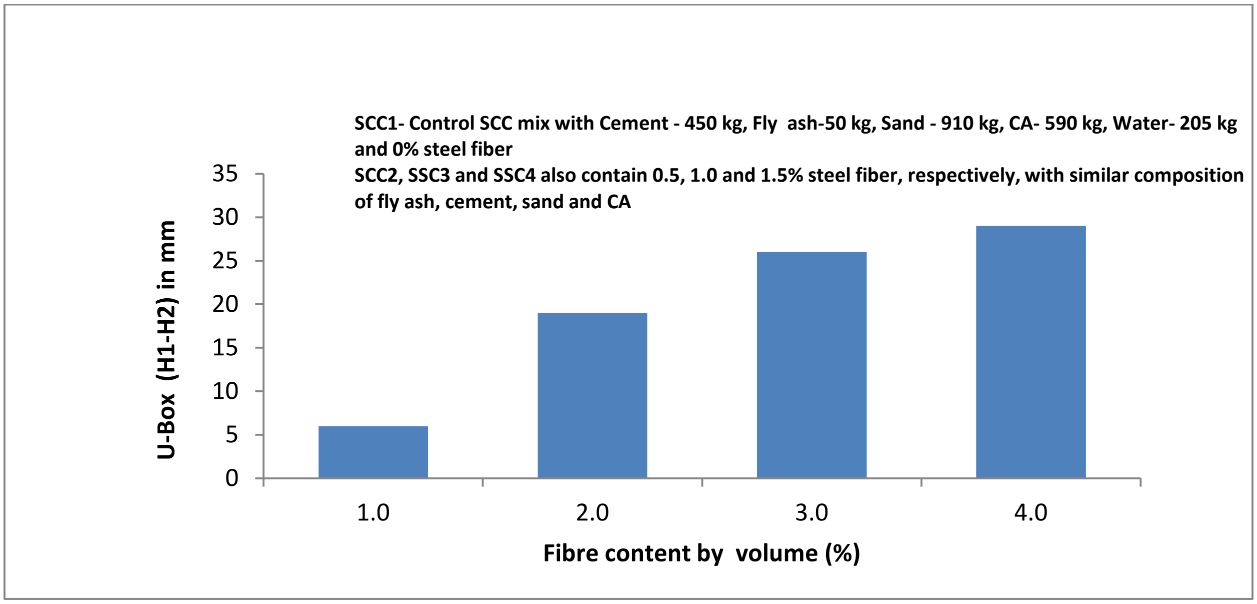

Figure 4.4: Effect of steel fiber content on U- box test of SCC

All fresh concrete properties are in good agreement to that of values given by European guidelines. Plate 4.1, 4.2, 4.3 shows various fresh concrete properties test results

Plate 4.1: Achieved slum flow by slump flow test

Plate 4.2: L- box test for fresh concrete

Plate 4.3: V-funnel test for fresh concrete

4.3 Hardened Concrete Properties

4.3.1 Compressive strength

In order to study the effects on compressive strength by adding fly ash and steel fibers to SCC. The cubes were casted for different proportions of steel fibers in SCC mixes and cured for 7 and 28 days. The test was conducted on ASTM capacity 3000 KN .The compressive strength test results are mentioned in Table 4.2, it is concluded that as the strength results are over 40 MPa of SCC mixes, these mixes can be considered as medium strength concrete. For 28 days compressive strength, fibers slightly improve the compressive strength of the mixes while for 7 days compressive strength; there is no clear effect of fibers on the compressive strength of the mixes.

This may be due to the chemical structure of the cement type and fly ash which is directly related to the strength development, as well as the randomly distributed fibers that contain entrapped air voids could possibly affect the results. Similarly the amount of coarse aggregate, fine aggregate and fly ash together with the mix proportioning is a key factor that is directly affecting the overall strength and durability properties of concrete.

The highest 7 days compressive strength obtained is 34.6 MPa for SCC3 with 1.0% fiber content by volume. The compressive strength of mixes after 7 days are comparable to those obtained after 28 days, which is because of the use of fly ash, which usually tends to increase the early strength of concrete. With 0.5 and 1.5% steel fiber content by volume in SCC2 and SCC4 increased 7 days compressive strength by 6.44% and 7.57% respectively, compared to control mix SCC1.

The highest 28 days compressive strength obtained is 48.5 MPa for SCC3 with 1.0% fiber content by volume. With increase of steel fiber contents by volume i.e. 0.5, 1.0 and 1.5% respectively in the mixes, improves the strength and the maximum improvement obtained is 12.16 % MPa from SCC3 with 1.0% fiber content by volume. Using 0.5 and 1.5% fiber content by volume in SCC2 and SCC4, 28 days compressive strength increased by 6.98% and 10.12% respectively, compared to control mix SCC1. The results can be compared to results given by Khaloo et al. (2014), Oliverira et al. (2013), Gencel et al. (2011), El- Dieb (2009), Anastasiou et al. (2014), Aydin (2007) and Kamal et al. (2013). Also, according to ACI, the strength is slightly affected by presence of fibers, hence to increasing its strength between 0 to 15 percent with 1.5

percent by volume of fibers (ACI 544.1, 1996).

Table 4.2: Results of compressive strength test of various SCC mixes

Mix ID	7 Days		28 Days	
	Comp. Strength (N/mm^2)	Avg. Comp. Strength (N/mm^2)	Comp. Strength (N/mm^2)	Avg. Comp. Strength (N/mm^2)
SCC1	30.8	30.5	41.5	42.6
	31.5		43.3	
	29.2		43.0	
SCC2	31.7	32.6	46.8	45.8
	33.2		45.7	
	32.9		44.9	
SCC3	35.9	34.6	47.8	48.5
	32.6		49.3	
	35.3		48.4	
SCC4	32.0	33.0	47.8	47.4
	32.8		48.2	
	34.2		46.2	

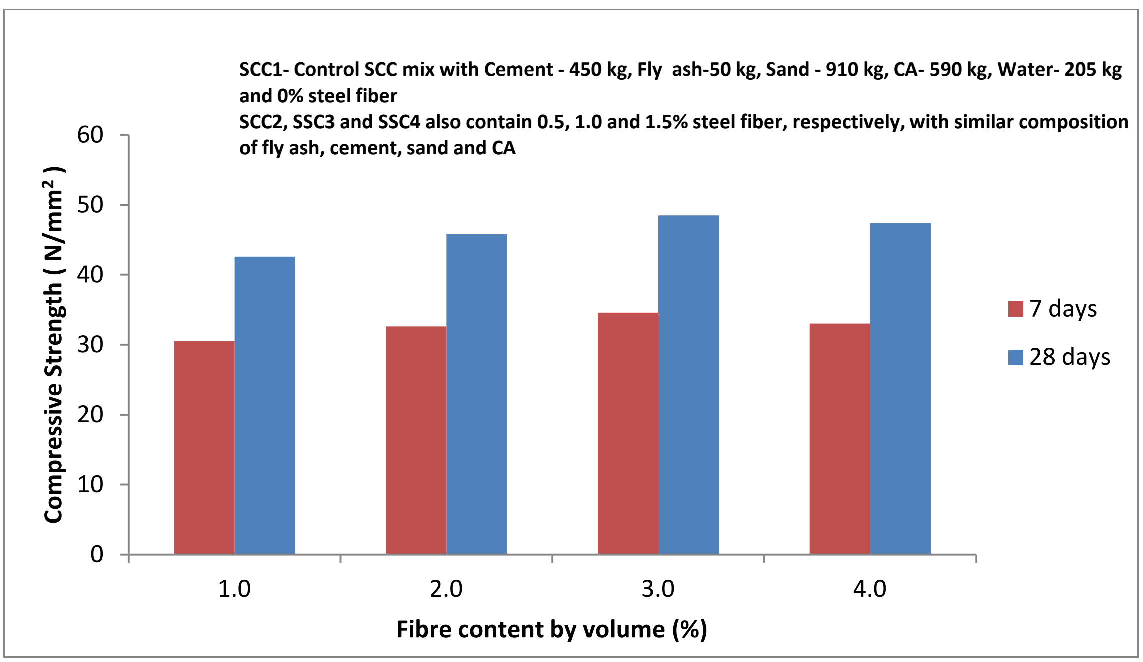

Figure 4.5: Effect of steel fiber content on compressive strength with age in SCC mixes

The effect of steel fiber content on compressive strength at ages (7 and 28 days) is plotted in Figure 4.5 shows variations in compressive strength with respect to ages of concrete.

The increase in compressive strength with the addition of steel fibers in 0.5 and 1.0% by volume may be associated with uniform dispersion of fine fibers through SCC of high flow ability. However, Steel fibers causes crack closing forces which led to increase the compressive strength. Whereas, a slight decrease of compressive strength is observed with the addition of 1.5% steel fibers by volume in SCC4 due to increase of entrapped air in the concrete which decreases the compressive strength.

4.3.2 Splitting tensile strength

The Splitting tensile strength tests were carried out at ages of 7 and 28 days and test results are mentioned in Table 4.3. As per results given in Table 4.3 it is concluded that with increasing the fiber contents increases the splitting tensile strength for all mixes. This in fact supports ACI which indicated that "the splitting tensile of mortar reinforced with steel fiber was reported to be about 2.5 times that of the unreinforced mortar when 3 percent fiber by volume was used and 2 times when 1.5 percent was used" (ACI 544.1, 1996).

The highest splitting tensile strength is 6.2 MPa for 28 days from SCC4 with 1.5% fiber content by volume. The increase in splitting tensile strength with 0.5, 1.0 and 1.5% fiber content by volume is 11.6, 32.1 and 38.7% respectively, compared to control mix SCC1, as shown in Figures 4.6. The results can be compared with Khaloo et al. (2014),Oulekbeche et al. (2010), Oliveriva et al. (2013) Gencel et al. (2011), Sahmaran and Yaman (2007), Akcay and Tasdemir (2012) and AC1 544.1,1996.

The strength increase is due to inclusion of steel fibers which is attributed to the mechanism of steel fibers in arresting crack progression. The presence of fibers restrains the development of internal micro-cracks and this contributes to increased splitting tensile strength. Moreover, the improved bonding of fiber- matrix which is provided by steel fibers with hooked ends, boosts pullout strength and this yield high increment in strength due to increase of fiber content.

Table 4.3: Results of splitting tensile strength test of various SCC mixes

Mix ID	7 Days		28 Days	
	STS (N/mm^2)	ASTS (N/mm^2)	STS (N/mm^2)	ASTS (N/mm^2)
SCC1	3.8	3.2	3.2	3.8
	2.8		4.2	
	3.0		4.0	
SCC2	4.3	3.6	4.2	4.3
	3.4		4.8	
	3.1		3.9	
SCC3	4.6	4.7	6.2	5.6
	4.4		5.0	
	5.1		5.6	
SCC4	6.4	5.3	5.8	6.2
	4.8		6.7	
	4.7		6.1	

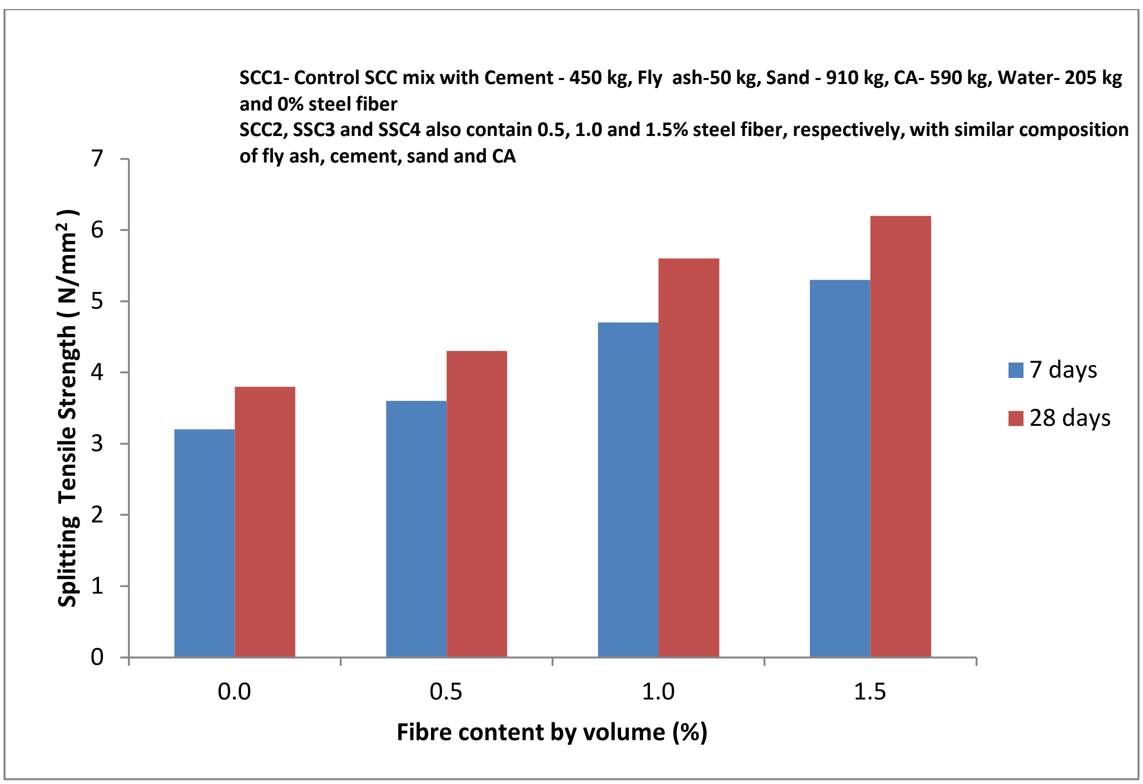

Figure 4.6: Effect of steel fiber content on splitting tensile strength

4.3.3 Flexural strength

The results of flexural strength test of all SCC mixes are given below in Table 4.4 and it is concluded that there is an increase in flexural strength of fiber reinforced concrete by increasing percentage of steel fiber content by volume.

The highest flexural strength is obtained 8.2 MPa of SCC4 with 1.5% steel fiber content by volume. The increase in flexural strength for SCC2, SCC3 and SCC4 with 0.5, 1.0 and 1.5% fiber content by volume is 14.06, 29.48 and 32.92% respectively, compared to control mix SCC1, as shown in Figure 4.7. The results may be compared with Rambo et al. (2014), Pajak and Ponikiewski (2015) and Khaloo et al. (2014), Akcay and Tasdemir (2012), Oliveriva et al. (2013), Aydin (2007), Gencel et al. (2011), Boulekbache et al. (2010) and Rambo et al. (2014).

Table 4.4: Results of flexural strength test of various SCC mixes

Mix ID	**7 Days**		**28 Days**	
	FS (N/mm^2)	**AFS (N/mm^2)**	**FS (N/mm^2)**	**AFS (N/mm^2)**
SCC1	5.6	5.1	5.2	5.5
	4.9		5.7	
	4.8		5.6	
SCC2	5.4	5.8	6.3	6.4
	6.3		6.1	
	5.7		6.8	
SCC3	6.8	6.7	7.6	7.8
	5.8		8.1	
	7.4		7.7	
SCC4	7.1	7.5	8.8	8.2
	6.8		8.0	
	8.4		7.8	

The major factors affecting flexural strength are volume fraction and aspect ratio (l/d) of fibers. With increase in l/d ratio and vol. of fibers, flexural strength increases, plotted in Figure 4.7.

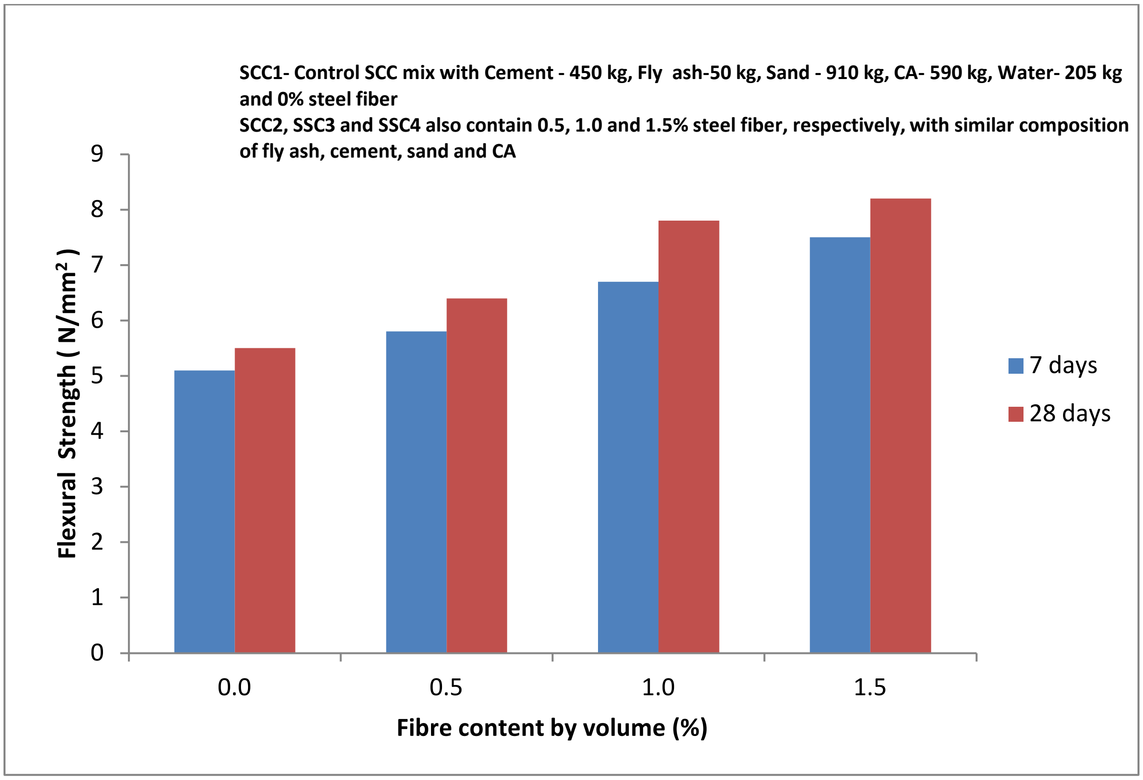

Figure 4.7: Flexural strength test results of SCC mixes

The flexural strength increases due to superior performance of specimens with steel fibers due to improved fiber- matrix- mortar bond provided by using steel fibers with hooked ends. This behavior is mainly attributed to the role of SF in releasing fracture energy around crack tips which is required to extent crack growing by transferring it from one side to another side. When tensile stress is transferred to fibers, the transferred load arrests and propagates the macro cracks and improves substantially. Randomly distributed steel fibers control cracks and stitch them. The higher the amount of steel fiber in concrete, the higher is the flexural strength.

4.3.4 Rapid chloride permeability test

The 28 days test results for resistance to penetration of chloride ions into the concrete are measured in terms of electric charge passed through the specimens in coulombs, for different SCC mixes with steel fibers as shown in Table 4.5 and Figure 4.8 by plotting a graph. From the results, it can be said that by adding fibers decrease the chloride ion penetration resistance of the concrete which supports the study that reports an increase in the total charge passing as the steel fiber volume fraction increases; this could be attributed to the electrical conductivity of the fibers (El-Dieb, 2009).

Table 4.6 shows the standard limits of chloride ion penetration according to ASTM. All chloride ion permeability values recorded indicate very low permeability according to standards classification (ASTM C 1202, 2010). Concrete electrical resistivity values support the findings in the RCPT. It should be noted that the resistivity values recorded for all mixes are very high which indicates very good protection to steel reinforcement against corrosion. The highest chloride ion penetration resistance is 766 Coulombs which is 74.15% for SCC4 with 1.5% steel fiber content by volume, as compared to control mix SCC1.

Table 4.5: Charge passed and rating for various SCC mixes

Mix ID	28 Days		
	Charge Passed in Coulombs	**Avg. Charge Passed in Coulombs**	**Chloride Ion Permeability**
SCC1	180	198	Very low
	220		
	195		
SCC2	570	530	Very low
	485		
	535		
SCC3	710	705	Very low
	760		
	645		
SCC4	750	766	Very low
	765		
	782		

The measurement concerns the chloride ions that come into concrete and those flowing through the samples. The current passed through SCC mixes are 198, 530, 705, 766 coulombs respectively at 28 days with inclusion of fiber content of 0.5, 1.0 and 1.5% by volume for SCC2, SCC3 and SCC4 respectively, as shown in Figure 4.14. The results can be compared with Cornaldesi and Moriconi (2014) Anastasiou et al. (2014), El-Dieb (2009), Oliveriva et al. (2013),

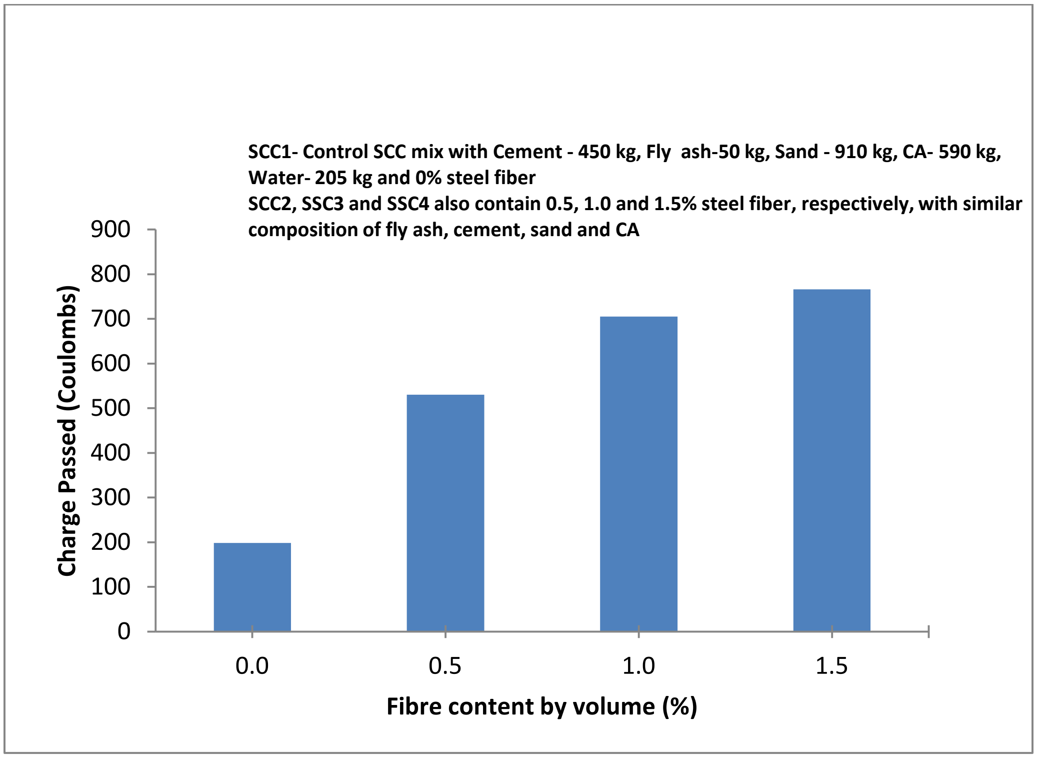

Figure 4.8: Effect of steel fiber content on charge passed

Table 4.6 given below, shows standard limits of chloride ion permeability according to ASTM C1202 (2010).

Table 4.6 Chloride ion penetrability based on charge passed

Charge Passed (Coulombs)	Chloride Ion Permeability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

4.3.5 Porosity

The porosity is the significant factor as it affects directly the durability of the SCC. The results of porosity of SCC concrete mixes are given in Table 4.7 and shown in Figure 4.9. The results indicate that the porosity decreased with increase in curing time. The main reason behind this is due to the additional or increased rate of hydration and/or pozzolanic reactions. There is more formation of C-S-H gel as a product of pozzolanic reaction between calcium hydroxide and silica. This gel fills the voids and increases the density of concrete. Lowest porosity is achieved by mix SCC1. SCC4 mix shows increase in porosity of about 6%, compared to controlled mix SCC1. As shown in Figure 4.9, the porosity decreased with increase in age. This is basically due to large formation of C-S-H gel, dense structure by fly ash is formed so porosity decreased. There is not any clear effect observed with the addition of fibers. Results are comparable to results given by El- Dieb (2009), Ponikiewski et al. (2015), Oliveriva et al. (2013), Acebes et al. (2011), Corinaldesi and Moriconi (2004)

Table 4.7: Porosity values of various SCC mixes

Mix ID	7 Days		28 Days	
	Porosity (%)	Avg. Porosity (%)	Porosity (%)	Avg. Porosity (%)
SCC1	9.6	9.6	9.6	9.3
	9.7		9.2	
	9.5		9.1	
SCC2	10.1	9.8	9.5	9.5
	9.8		9.7	
	9.5		9.3	
SCC3	10.3	10.1	10.0	9.8
	10.4		9.9	
	9.9		9.5	
SCC4	10.1	10.2	10.0	9.9
	10.2		10.1	
	10.4		9.6	

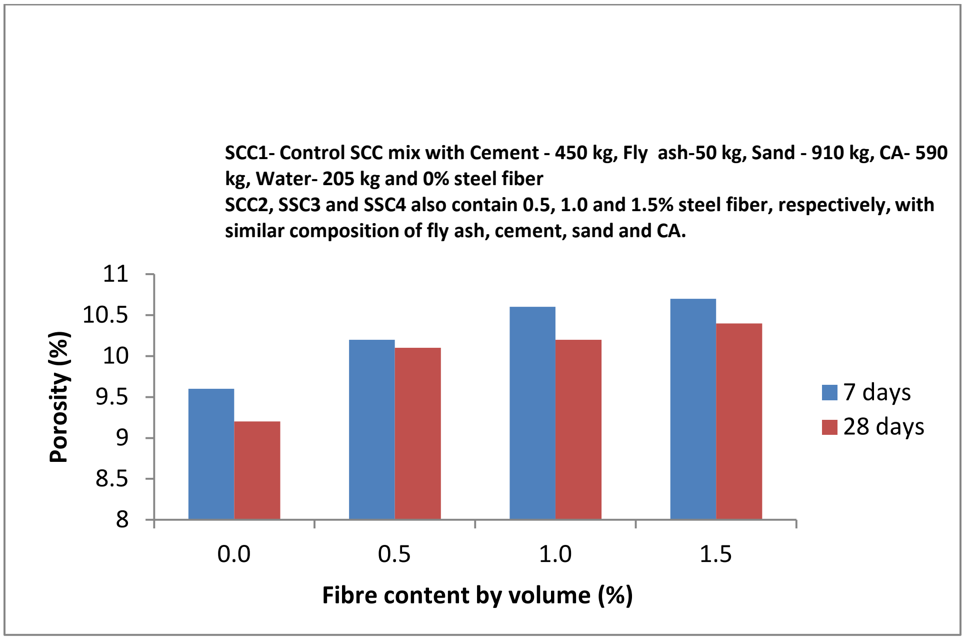

Figure 4.9: Porosity of various SCC mixes with respect to age

4.3.6 Ultra sonic pulse velocity test

The results of ultra sonic pulse velocity (UPV) test of all SCC mixes are given in Table 4.8 and plotted in Figure 4.10 and it is concluded that using fibers slightly decrease the ultrasonic pulse velocity of the SCC mixes. The reason could be due to the availability of voids content in the mixes with fibers more than the voids content in the control mix SCC which will decrease the time needed for ultrasonic wave to pass, thus in directly proportional the velocity will be increased. Besides, the steel fibers in the cubes are randomly oriented, when the waves passes through the fibers, may be deflected to other directions rather than passed straight forward to the end of the cube.

The highest pulse velocity is 4.7 km/s obtained from the control mix SCC1 and the minimum pulse velocity is 3.9 km/s from SCC4 which is 17% less as compared to SCC1 as shown in Figure 4.10. The results can be compared with Cebel et al. (2011), Gencel et al. (2011), Sahmaran and Yaman (2007), Acebes et al. (2011).

Table 4.8: Results of ultra sonic pulse velocity test of various SCC mixes

Mix ID	7 Days		28 Days	
	Ultra Sonic Pulse Velocity (km/s)	Average Ultra Sonic Pulse Velocity (km/s	Ultra Sonic Pulse Velocity (km/s)	Average Ultra Sonic Pulse Velocity (km/s
SCC1	4.6	4.6	5.1	4.7
	4.3		4.6	
	4.7		4.4	
SCC2	4.3	4.2	4.2	4.4
	4.5		4.7	
	3.8		4.3	
SCC3	4.2	4.3	4.7	4.5
	4.5		4.8	
	4.2		4.0	
SCC4	3.8	3.6	4.0	3.9
	3.6		4.3	
	3.4		3.5	

Note that a general suggestion for the classification of quality of concrete by UPV technique for 2400 kg/m^3 density concretes. Concretes are classified as excellent, good, doubtful, poor, and very poor for 4.5 km/s and above, 3.50 – 4.50 km/s, 3.0 – 3.5 km/s, 2.0 – 3.0 km/s and 2.0 km/s and below UPV values, respectively (Whitehurst, 1951). The lower limit of good quality concrete is between 4.1 and 4.7 km/s UPV values. By using these proposed classification techniques, all produced concretes in this research are excellent quality (Jones and Gatfield, 1955).

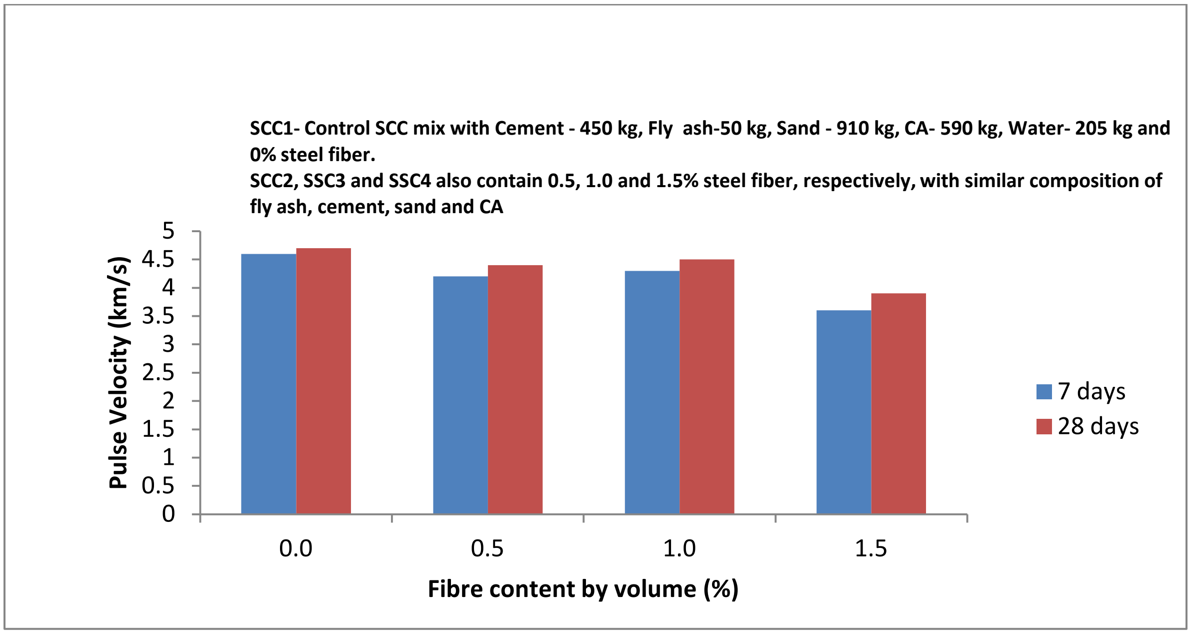

Figure 4.10: Effect of steel fiber content on ultra sonic pulse velocity test

It is concluded that using steel fibers, slightly decrease the UPV of SCC mixes. The reason could be due to availability of voids in the mixes with steel fibers more than the voids in control SCC1 mix.

CHAPTER 5 CONCLUSIONS

5.1 General

The strength and durability characteristics of Self compacting concrete (SCC) incorporating fly ash (10%) and steel fibers content 0.5, 1.0 and 1.5% by volume, have been computed. The inclusion of fly ash and steel fibers improved the concrete properties in fresh state i.e. deformability, passing ability, filling ability and segregation resistance as well as in hardened state i.e. mechanical and durability properties. The improvement in properties of SCC is because of enhancement in interfacial or bond strength of steel fibers and pore refinement by fly ash in the concrete.

On the basis of present study following conclusions are been drawn.

5.2 Fresh Concrete Properties

The present results show that it is possible to design a SCC mix incorporating 10% fly ash and steel fibers in 1% by volume. The SCC mixes have a slump flow in range of 600 - 800 mm, V-funnel time in range of 4 - 10 sec; L- box ratio was greater than 0.8 for all mixes and difference in height of concrete in two compartments in U- box in the range of 5 – 40 mm. With increase of steel fiber content by volume fractions the workability decreased.

5.3 Compressive Strength

For constant water binder ratio, compressive strength increased up to 12.16% with the inclusion of 1.0% steel fibers by volume. With more than 1.0% steel fiber content by volume, a slight decrease in strength was observed due to increase of entrapped air voids but its value was still higher than controlled mix (SCC1). SCC mixes develop compressive strength ranging from 30.5 to 34.6 MPa and from 42.6 to 48.5 MPa for 7 and 28 days, respectively.

The increase of about 11.8% strength at 7 days and 12.16% strength at 28 days were observed with increase of steel fiber content from controlled mix (SCC1) to SCC3 with 1.0% steel fiber content.

5.4 Splitting Tensile Strength

The splitting tensile strength increased with inclusion of steel fibers. SCC mixes develop split tensile strength ranging from 3.2 to 5.7 MPa and from 3.8 to 6.2 MPa at 7 and 28 days, respectively.

The increase in splitting tensile strength of about 44% at 7 days and 39% at 28 days were observed with increase of steel fiber content from controlled mix (SCC1) to SCC4 with 1.5% steel fiber content.

5.5 Flexural Strength

The flexural strength increased with inclusion of steel fibers up to 1.5% by volume. SCC mixes develop flexural tensile strength ranging from 5.7 to 7.5 MPa and from 5.5 to 8.2 MPa at 7 and 28 days, respectively.

The increase in flexural strength of about 24% at 7 days and 33% at 28 days were observed with increase of steel fiber content from controlled mix (SCC1) to SCC4 with 1.5% steel fiber content.

5.6 Rapid Chloride Permeability Test (RCPT)

SCC mixes made with steel fibers and fly ash reduced the rapid chloride ion penetrability. The increase in steel fiber content by volume in concrete increases the charge passed due to electrical conductivity of steel fibers. Very low permeability was achieved by controlled mix (SCC1). Though increase in charge passing is observed with inclusion of steel fibers as compare to controlled mix, but very low range (100 – 1000) at 28 days was recorded for all SCC mixes.

5.7 Porosity

With the inclusion of steel fibers porosity decreased slightly, with increase in curing time due to increased rate of hydration with time. The lowest porosity is obtained by controlled mix (SCC1).

With the inclusion of steel fibers, porosity is increased from 9.6 to 10.2% and from 9.3 to 9.9% for 7 and 28 days, respectively.

5.8 Ultra Sonic Pulse Velocity

The ultra sonic pulse velocity of SCC mixes decreases slightly with increase of steel fiber content by volume due to availability of voids in mixes with steel fibers than controlled mix (SCC1), which increases the time required for ultra sonic waves to pass as steel fibers in cubes are randomly oriented. The ultra sonic pulse waves may be deflected to other directions rather than straight forward to the other end of cube thus velocity is decreased.

The decrease in ultra sonic pulse velocity is about 22% at 7 days and 17% at 28 days were observed with increase of steel fiber content from controlled mix (SCC1) to SCC4 with 1.5% steel fiber content.

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