STRENGTH AND PERMEABILITY STUDIES OF SELF-COMPACTING CONCRETE INCORPORATING FLY ASH AND SILICA FUME

A thesis submitted in partial fulfilment of the requirements for the award of degree of
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Submitted by

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CERTIFICATE

This is to certify that the work presented in Thesis entitled "Strength and Permeability studies of Self-Compacting Concrete with Fly ash and Silica fume" submitted by, **Gurpreet Singh Roll No. 800922003** in partial fulfilment of the requirements for the award of **Masters of Engineering in Civil (Structures) at Thapar University, Patiala**, is an authentic record of student's own work carried out under our supervision and guidance. The embodied in this thesis has not been submitted anywhere for award of any other degree.

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ABSTRACT

A self-compacting concrete (SCC) is the one that can be placed in the form and can go through obstructions by its own weight and without the need of vibration. Since its first development in Japan in 1988, SCC has gained wider acceptance in Japan, Europe and USA due to its inherent distinct advantages. The major advantage of this method is that SCC technology offers the opportunity to minimize or eliminate concrete placement problems in difficult conditions. And it avoids having to repeat the same kind of quality control test on concrete, which consumes both time and labour. Construction and placing becomes faster & easier. It eliminates the need for vibration & reducing the noise pollution. It improves the filling capacity of highly congested structural members.SCC provides better quality especially in the members having reinforcement congestion or decreasing the permeability and improving durability of concrete.

The primary aim of this study is to explore the feasibility of using SCC by examining its fresh properties, hardened properties i.e. compressive strength, splitting tensile strength, rapid chloride permeability. An extensive literature survey was conducted to explore the present state of knowledge on the fresh and hardened properties of self-consolidating concrete. However, because it usually requires a larger content of binder and chemical admixtures compared to ordinary concrete, its material cost is generally 20–50% higher, which has been a major hindrance to a wider implementation of its use. There is growing evidence that incorporating high volumes of mineral admixtures and micro-fillers as partial replacement for Portland cement in SCC can make it cost effective.

This research consists of: (i) development of a suitable mix for SCC that would satisfy the requirements of the plastic state; (ii) casting of concrete samples and testing them for compressive strength, splitting tensile strength, rapid chloride permeability. Local aggregates, cement, admixtures and additives produced by the local suppliers were used by in this work. The significance of this work lies in its attempt to provide some performance data of SCC so as to draw attention to the possible use of SCC.

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CHAPTER: 1 INTRODUCTION

1.1 General

In general, a newly placed concrete is compacted by vibrating equipment to remove the entrapped air, thus making it dense and homogeneous; Compaction is the key to producing good concrete with optimum strength and durability (The Concrete Society and BRE, 2005). However, in Japan in the early 1980's, because of the increasing reinforcement volumes with smaller bar diameters and a reduction in skilled construction workers, full compaction was difficult to obtain or judge, leading to poor quality concrete (Okamura and Ouchi, 1999).

Professor Okamura therefore proposed a concept for a design of concrete independent of the need for compaction. Ozawa and Maekawa produced the first prototype of SCC at the University of Tokyo in 1988 (Ozawa et al., 1989; RILEM TC 174 SCC, 2000).

Since that time SCC has gone from a laboratory novelty to practical applications all over the world. The increasing numbers of papers published every year that deal with all aspects of SCC, e.g. mix design, rheological and physical properties and applications in practice indicate research on this technology is Thriving. Recommendations on the design and applications of SCC in construction have now been developed by many professional societies, including the American Concrete Institute (ACI), the American Society for Testing and Materials (ASTM), Centre for Advanced Cement-Based Materials (ACBM), Precast Consulting Services (PCI) and Réunion Internationale des Laboratoires et Experts des Matériaux, systèmes de construction et ouvrages (RILEM) etc. Symposiums and workshops on this topic have been organized by these societies and several test methods have been or are in the process of standardization.

1.2 Historical Development of Self-Compacting Concrete

Self-compacting concrete, in principle, is not new. Special applications such as underwater concreting have always required concrete, which could be placed without the need for compaction (Bartos, 2000). In such circumstances vibration was simply impossible. Early self-compacting concretes relied on very high contents of cement paste and, once super plasticizers became available, they were added in the concrete mixes. The mixes required specialized and well-controlled placing methods in order to avoid segregation, and the high contents of cement paste made them prone to shrinkage. The overall costs were very high and applications remained very limited.

The introduction of “modern” self-levelling concrete or self-compacting concrete (SCC) is associated with the drive towards better quality concrete pursued in Japan around 1983, where the lack of uniform and complete compaction had been identified as the primary factor responsible for poor performance of concrete structures (Dehn et al., 2000). Due to the fact that there were no practical means by which full compaction of concrete on a site was ever to be fully guaranteed, the focus therefore turned onto the elimination of the need to compact, by vibration or any other means. This led to the development of the first practicable SCC by researchers Okamura and Ozawa, around 1986, at the University of Tokyo and the large Japanese contractors (e.g. Kajima Co., Maeda Co., Taisei Group Co., etc.) quickly took up the idea. The contractors used their large in-house research and development facilities to develop their own SCC technologies. Each company developed their own mix designs and trained their own staff to act as technicians for testing on sites their SCC mixes. A very important aspect was that each of the large contractors also developed their own testing devices and test methods. In the early 1990's there was only a limited public knowledge about SCC, mainly in the Japanese language. The fundamental and practical know-how was kept secret by the large corporations to maintain commercial advantage. 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 continued in mix-design and placing of underwater concrete where new admixtures were producing SCC mixes with performance matching that of the Japanese SCC concrete (e.g. University of Paisley / Scotland, University of Sherbrooke / Canada) (Ferraris,1999).

1.3 Motive for Development of Self-Compacting Concrete

The motive for development of self-compacting concrete was the social problem on durability of concrete structures that arose around 1983 in Japan. Due to a gradual reduction in the number of skilled workers in Japan's construction industry, a similar reduction in the quality of construction work took place. 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 Fig.1.1. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, were carried out by researchers Ozawa and Maekawa (Bartos, 2000) at the University of Tokyo.

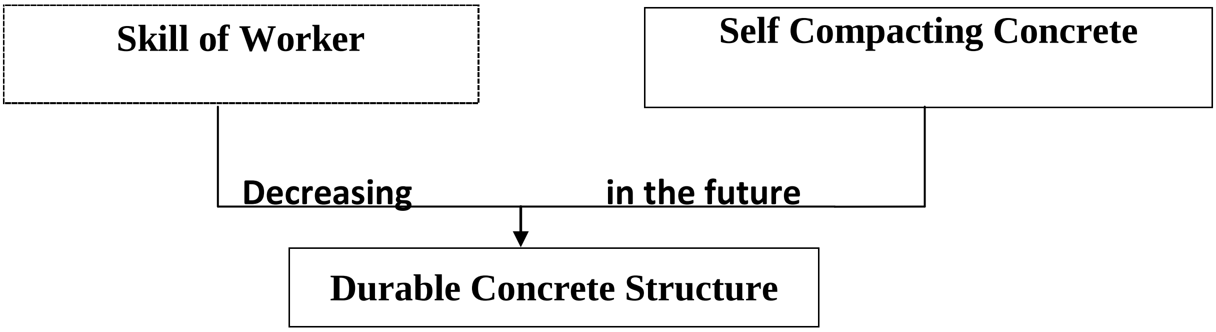

Fig.1.1: Necessity of Self-Compacting Concrete (Ouchi and Hibino, 2000).

During their studies, they found that the main cause of the poor durability performances of Japanese concrete in structures was the inadequate consolidation of the concrete in the casting operations. By developing concrete that self-consolidates, they eliminated the main cause for the poor durability performance of the concrete. By 1988, the concept was developed and ready for the first real-scale tests and at the same time the first prototype of self-compacting concrete was completed using materials already on the market. The prototype performed satisfactorily with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties and was named “High Performance Concrete.” At almost the same time, “High Performance Concrete” was defined as a concrete with high durability due to low water-cement ratio by professor Aitcin (Ouchi et al., 1996). Since then, the term high performance concrete has been used around the world to refer to high durability concrete. Therefore, Okamura (1997) has changed the term for the proposed concrete to “Self-Compacting High Performance Concrete.”

1.4 Construction Issues

By employing self-compacting concrete, the cost of chemical and mineral admixtures is compensated by the elimination of vibrating compaction and work done to level the surface of the normal concrete (Khayat et al., 1997). However, the total cost for a certain construction cannot always be reduced, because conventional concrete is used in a greater percentage than self-compacting concrete. SCC can greatly improve construction systems previously based on conventional concrete requiring vibrating compaction. Vibration compaction, which can easily cause segregation, has been an obstacle to the rationalization of construction work. Once this obstacle has been eliminated, concrete construction could be rationalized and a new construction system, including formwork, reinforcement, support and structural design, could be developed. The main reasons for the employment of self-compacting concrete can be summarized as follows:

- To shorten construction period.
- To assure compaction in the structure - especially in confined zones where vibrating compaction is difficult.
- To eliminate noise due to vibration - effective especially at concrete products plants.

The method for achieving self-compactability 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 confined zone reinforcing bars.

Okamura, Ozawa (2003) have employed the following methods to achieve self-compactability:

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

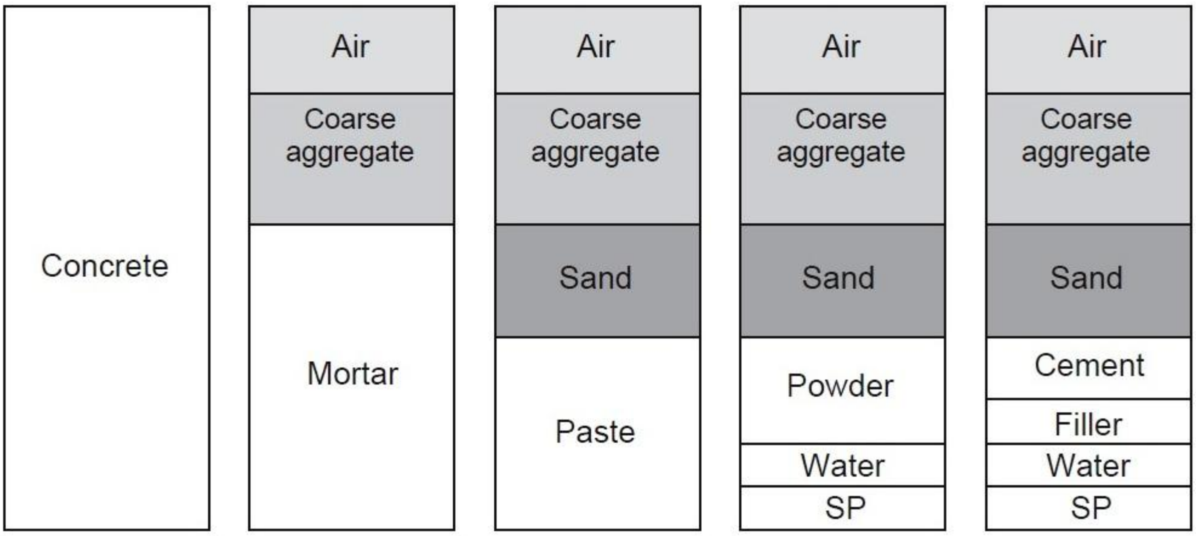

Fig 1.2: The schematic composition of SCC (Brouwers, Radix, 2005)

The frequency of collision and contact between aggregate particles can increase as the relative distance between the particles decreases and then internal stress can increase when concrete is deformed, particularly near obstacles. Research has found that the energy required for flowing is consumed by the increased internal stress, resulting in blockage of aggregate particles. Limiting the coarse aggregate content, whose energy consumption is particularly intense, to a level lower than normal is effective in avoiding this kind of blockage. Highly viscous paste is also required to avoid the blockage of coarse aggregate when the concrete flows through obstacles. When the concrete is deformed, paste with a high viscosity also prevents localized increases in internal stress due the approach of coarse aggregate particles. High deformability can be achieved only by the employment of a super-plasticizer, keeping the water-powder ratio to a very low value.

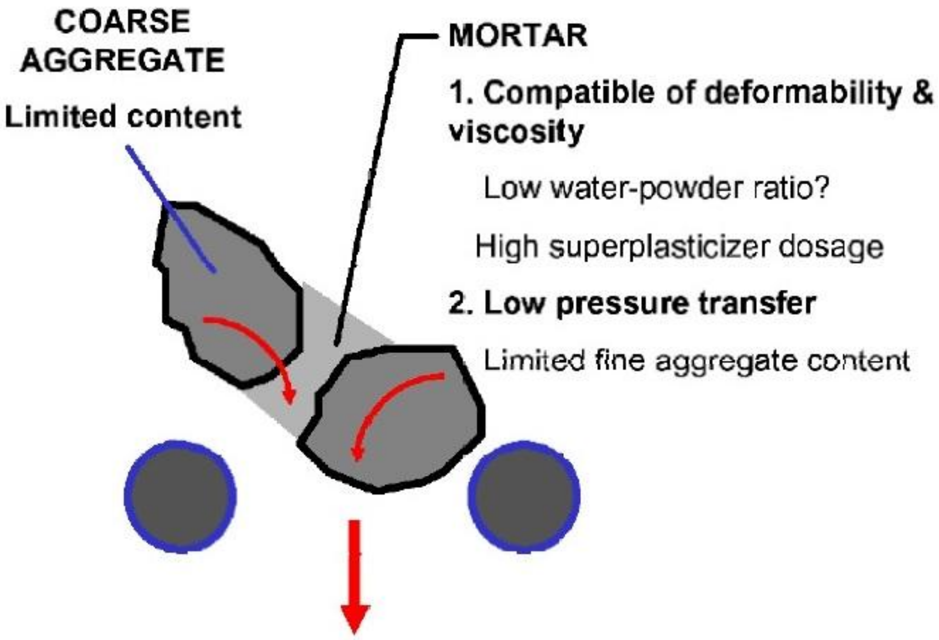

Fig 1.3: Mechanism for achieving self-compactability. (Okamura, Ouchi, 2003)

1.4.1 SCC Production

- Production of SCC requires more experience and care than the conventional vibrated concrete. The plant personnel would need training and experience to successfully produce and handle SCC. In the beginning, it may be necessary to carry out more tests than usual to learn how to handle SCC and gain the experience.
- Before any SCC is produced at the plant and used at the job site, the mix must be properly designed and tested to assure compliance with the project specifications. The ingredients and the equipment used in developing the mix and testing should be the same ingredients and equipment to be used in the final mix for the project.
- Most common concrete mixers can be used for producing SCC. However, the mixing time may be longer than that for the conventional vibrated concrete. SCC is more sensitive to the total water content in the mix. It is necessary to take into account the moisture/water content in the aggregates and the admixtures before adding the remaining water in the mix. The mixer must be clean and moist, and contains no free water.
- Admixtures for the SCC may be added at the plant or at the site. There is cost benefit in adding the admixtures at the site. Conventional ready-mix concrete can be bought at a lower cost than the cost of SCC bought from a ready-mix supplier.

1.4.2 Transportation

- The truck drivers should be given oral and written instructions for handling SCC. The truck drivers must check the concrete drum before filling with SCC to make sure that the drum is clean and moist, but with no free water. Extra care must be taken for long deliveries. In addition to the usual information, the delivery note should show the following information:
  1) Slump flow - target value and acceptable range.
  2) Production time - time when it was produced.
  3) Instruction for adding admixtures at the site, if allowed.
- The truck drivers should not be allowed to add water and/or admixtures during transit.

1.4.3 Form System

- All commonly used form materials are suitable for SCC. For surface quality of SCC, wood is better than plywood, and plywood is better than steel. More pores seem to form on the surface when the form skin is colder than the SCC. During cold weather placement of SCC, it may be necessary to insulate the formwork to maintain temperature and normal setting time. SCC is more sensitive to temperature during the hardening process than the conventional vibrated concrete.
- Due to the cohesiveness of SCC, the formwork does not need to be tighter than that for conventional vibrated concrete.
- Higher form pressures than normal were not observed even at high rate of concrete placement. However, it is recommended that the formwork be designed for hydrostatic pressure, unless testing has shown otherwise.

1.4.4 Casting on Site

- A pre-SCC placement meeting with all personnel involved in the SCC placement would be beneficial. The SCC placement plan, including QC/QA, and the roles and responsibilities of the field personnel should be explained and understood.
- In addition to the normal testing, the slump flow, T50 and L-box tests are useful to check SCC at the job site before placement.
- SCC can flow horizontally a distance of 15 to 20m without segregation. A well-designed SCC may have a free fall of as much as 8m without segregation. However, it is recommended that the distance of horizontal flow be limited to 10m and the vertical free fall distance be limited to 5m.

- For deck slab of a bridge, it would be difficult for the SCC to flow too far. This could be handled by designing an SCC with a lower slump flow. With a lower slump flow, a bridge deck with a slope of 2% could also be accomplished.
- If an SCC placement is interrupted and the concrete has started to harden, it would be necessary to wake up the placed concrete by striking a stick or board into the concrete several times before starting the placement again.
- SCC takes some time before the hardening starts, especially during cold weather conditions. When it starts to harden, the process is very rapid, which can cause problems in levelling and treating large surface areas.

1.4.5 Surface Finishing and Curing

- Finishing and curing of SCC can follow the good practices of super-plasticized high performance concrete. Surface of SCC should be roughly levelled to the specified dimensions, and the final finishing applied as necessary before the concrete hardens.
- SCC tends to dry faster than conventional vibrated concrete, because there is little or no bleeding water at the surface. SCC should be cured as soon as practicable after placement to prevent surface shrinkage cracking.

1.4.6 Cold Joint

- When placing a new layer of SCC on old SCC, the bond between the old and new SCC is equal to or better than in the case of conventional vibrated concrete. Normal vibration will not destroy the concrete, such as in the case of placing conventional vibrated concrete on fresh SCC. This may be necessary when the surface slope is greater than practicable for SCC.

1.5 World-wide Current Situation of Self-Compacting Concrete

Self-compacting concrete has already been used in several countries. In Japan, major construction projects included 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 production (Okamura, 1997). Currently, the percentage of self-compacting concrete in annual product of ready-mixed concrete (RMC), as well as precast concrete (PC), in Japan is around 1.2% and 0.5% of concrete products. In the United States, the precast industry is also leading SCC technology implementation through the Precast/Pre-stressed Concrete Institute (PCI) which has done some research on the use of SCC in precast/pre-stressed concretes starting with 1999. It is estimated that the daily production of SCC in the precast/pre-stressed industry in the United States will be 8000 m^3 in the first quarter of 2003 (around 1% of the annual ready-mix concrete). Furthermore, several state departments of transportation in the United States (23 according to a recent survey).

Bartos, (2000) are already involved in the study of SCC. With such a high level of interest from the construction industry, as well as manufacturers of this new concrete, the use of SCC should grow at a tremendous rate in the next few years in the United States. However, even if it is made from the same constituents the industry has used for years, the whole process, from mix design to placing practices, including quality control procedures, needs to be reviewed and adapted in order for this new technology to be applied properly. Research regarding the self-compacting concrete was also carried out in Canada, few years after the concept was introduced in Japan. Institute for Research in Construction, Canadian Precast/Pre-stressed Concrete Institute, CONMET-ICON, and ISIS are some of the bodies which studied various aspects of the new technology. The introduction of the SCC in Europe is largely connected with the activities of the international association RILEM, France, particularly of its Technical Committee TC145-WSM on “Workability of Fresh Special Concrete Mixes” (Dhir and Dyer, 1999). The TC145-WSM was founded in 1992 and immediately attracted expert memberships from all over the world. The aim was to look at the production stage of a number of “special” concretes and identify workability parameters and other characteristics of the mixes in their fresh state that governed the reliable and economical achievement of the “special” or “high-performance” parameters the concretes offered. As the importance of the SCC became widely recognized, other European countries, Germany, Sweden, UK, Denmark, Netherlands, Norway, Finland, etc., have decided to keep up with the developments in this area. For example, in Sweden, the SCC market share was at five percent in RMC and PC in 2002, and was expected to double in 2003. Housing and tunnelling, as well as bridge construction for the Swedish National Road Administration were the main areas of use for SCC. In the Netherlands and Germany, the precast industry is mainly driving the development of SCC, with an expected eight percent of market share in 2003 in Netherlands. Today, self-compacting concrete is being studied worldwide, with as per presented at almost every concrete-related conference, but until now - year 2003 - there is no universally adopted standardized test method for evaluation of self-compatibility of this concrete.

Currently, the use of self-compacting concrete is being rapidly adopted in many countries. The use of self-compacting concrete should overcome concrete placement problems associated with the concrete construction industry. However, there still is a need for conducting more research and development work for the measurement and standardization of the methods for the evaluation of the self-compacting characteristics of SCC.

1.6 Need for This Research

SCC has not gained much local acceptance though it has been promoted in the Middle East for the last five years. Awareness of SCC has spread across the world, prompted by concerns with poor consolidation and durability in case of conventionally vibrated Normal concrete. The reluctance in utilizing the advantages of SCC is,

1. Lack of research or published data pertaining to locally produced SCC.
2. The potential problems for the production of SCC, if any, with local marginal aggregates and the harsh environmental conditions prevailing in the region.

Therefore, there is a need to conduct studies on SCC.

1.7 Fly Ash

Fly ash is one of the most extensively used by-product materials in the construction field resembling Portland cement (Pfeifer, 1969). It is an inorganic, non-combustible, finely divided residue collected or precipitated from the exhaust gases of any industrial furnace (Halstead, 1986). Most of the fly ash particles are solid spheres and some particles, called cenospheres, are hollow Fig.1.3. (Kosmatka et al., 2002). Also present are plerospheres, which are spheres containing smaller spheres inside. The particle sizes in fly ash vary from less than 1 μm to more than 100 μm with the typical particle size measuring less than 20 μm. Their surface area is typically 300 to 500 m2/kg, although some fly ashes can have surface areas as low as 200 m2/kg and as high as 700 m2/kg. Fly ash is primarily silicate glass containing silica, alumina, iron, and calcium. The relative density or specific gravity of fly ash generally ranges between 1.9 and 2.8 and the colour is generally gray or tans (Halstead, 1986).

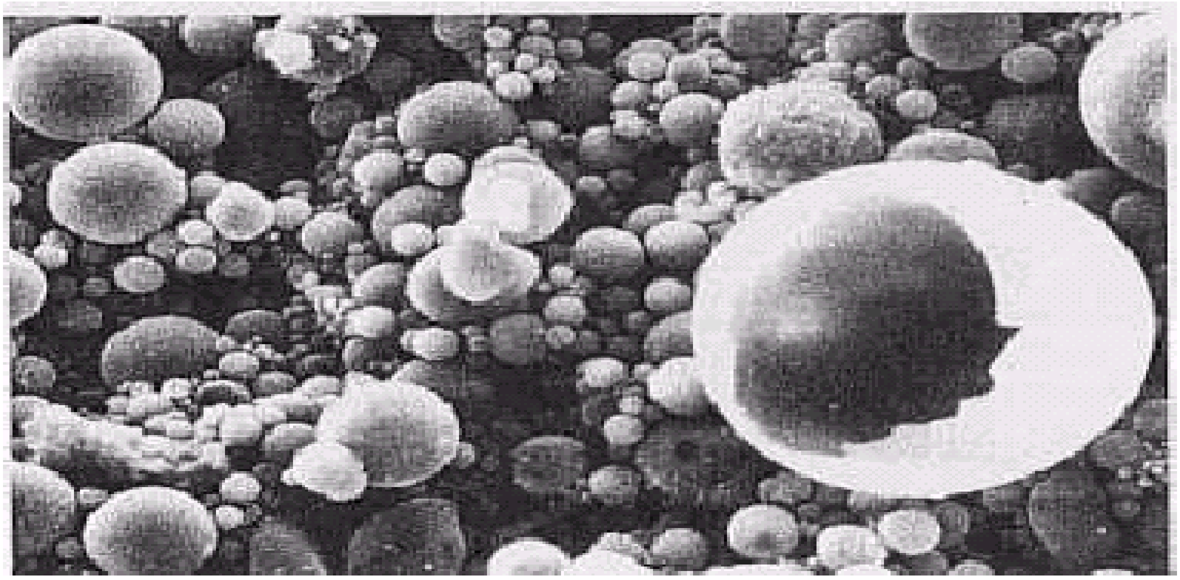

Fig.1.4: SEM micrograph of fly ash particles (Kosmatka et al., 2002).

Classification of Fly Ash

ASTM – C 618-93 categorizes natural pozzolans and fly ashes into the following three categories: -

1. Class N Fly ash: Raw or calcined natural pozzolans such as some diatomaceous earths, opaline chert and shale, stuffs, volcanic ashes and pumice come in this category. Calcined kaolin clay and late rite shale also fall in this category of pozzolans.

2. Class F Fly ash: Fly ash normally produced from burning anthracite or bituminous coal falls in this category. This class of fly ash exhibits pozzolanic property but rarely if any, self-hardening property.

3. Class C Fly ash: Fly ash normally produced from lignite or sub- bituminous coal is the only material included in this category. This class of fly ash has both pozzolanic and varying degree of self cementitious properties. (Most class C fly ashes contain more than 15 % CaO. But some class C fly ashes may contain as little as 10 % CaO.

Table 1.1: Requirements for fly ash and natural pozzolans for use as a mineral admixture in Portland cement concrete as per ASTM C 618-93.

Requirements	**Fly Ash Classification**		
	N	**F**	**C**
Chemical Requirements			
SiO_2 + Al2O_3 + Fe_2O_3, min %	70	70	70
SO_3, max %	4	5	5
Moisture content, max %	3	3	3
Loss on ignition, max %	10	6	6
Physical Requirements			
Amount retained when wet sieved on 45 m.Sieve, max %	34	34	34
Pozzolanic activity index, with Portland cement at 28 days, min % of control	75	75	75
Pozzolanic activity index, with lime, at 7 days,min (MPa)	5.5	5.5	-
Water requirement, max % of control	115	105	105
Autoclave expansion or contraction, max	0.8	0.8	0.8
Specific gravity, max variation from	5	5	5
Percentage retained on 45 sieve, max variation, and percentage points from	5	5	5

Table 1.2: Chemical Requirements

S. No.	**Characteristics**	**Requirement (%)**
1	Silicon dioxide (SiO_2) + aluminium oxide (Al_2O_3) + iron oxide (Fe2O3), percent by mass, Min.	70
2	Silicon dioxide (SiO_2), percent by mass, Min.	35
3	Magnesium oxide (MgO), percent by mass, Max.	5
4	Total sulphur as sulphur trioxide (SO_3), percent by mass,Max	2.75
5	Available alkalis as sodium oxide (Na_2O), percent by mass, Max.	1.5
6	Loss on Ignition, percent by mass, Max.	12
7	Moisture content, percent by mass	3

1.8 Silica Fume

Silicon, ferrosilicon and other silicon alloys are produced by reducing quartz, with coal and iron or other ores, at very high temperatures (2000°C) in electric arc furnaces (St John,1998). Some silicon gas or fume is produced in the process, which reaches the top of the furnace with other combustion gases, where it becomes oxidized to silica in contact with the air and then condenses as < 0.1 μm to 1 μm spherical particles of amorphous silica. This material is usually known as silica fume. It is also referred to as micro silica or more properly, condensed silica fume (csf). Silica fume is an ultra fine powder, with individual particle sizes between 50 and 100 times finer than cement, comprising solid spherical glassy particles of amorphous silica (85-96 percent SiO2). However, the spherical particles are usually agglomerated so that the effective particle size is much coarser. Silica fume used in concrete derives from the manufacture of ferrosilicon alloys and is modified by densification, micropelletization or slurrification, to facilitate transportation and handling. Condensed silica fume has a surface area of about 20,000 m^2/kg and a relative density generally in the range of 2.20 to 2.5 (Kosmatka et al., 2002).

The pozzolanic reactions take place when silica fume is added to the concrete mixture, and the amorphous silica, which is the major component of the pozzolan, reacts with calcium hydroxide formed from the hydration of the calcium silicates with the resulting product being a calcium silicate hydrate (C-S-H) (Mindess et al., 2003). Usually, after micro-silica is being added to the concrete mix, the matrix of micro silica concrete becomes very dense (St John, 1998). This denseness effect has been attributed to the extreme fineness of micro silica, due to the fact that

50,000 to 100,000 microspheres exist for every cement grain, allowing micro-silica hydration products to infill the water spaces usually left within the cement hydrates, as showed in Figure 1.3. Silica fume is used in amounts between 5% and 10% by mass of the total cementitious material, in applications where high degree of impermeability and high compressive strength are needed in concrete. In some situations, the water demand of concrete containing silica fume increases with increasing amounts of silica fume, unless a water reducer or plasticizer is used. Some lean mixes may not experience an increase in water demand when only a small amount (less than 5%) of silica fume is present.

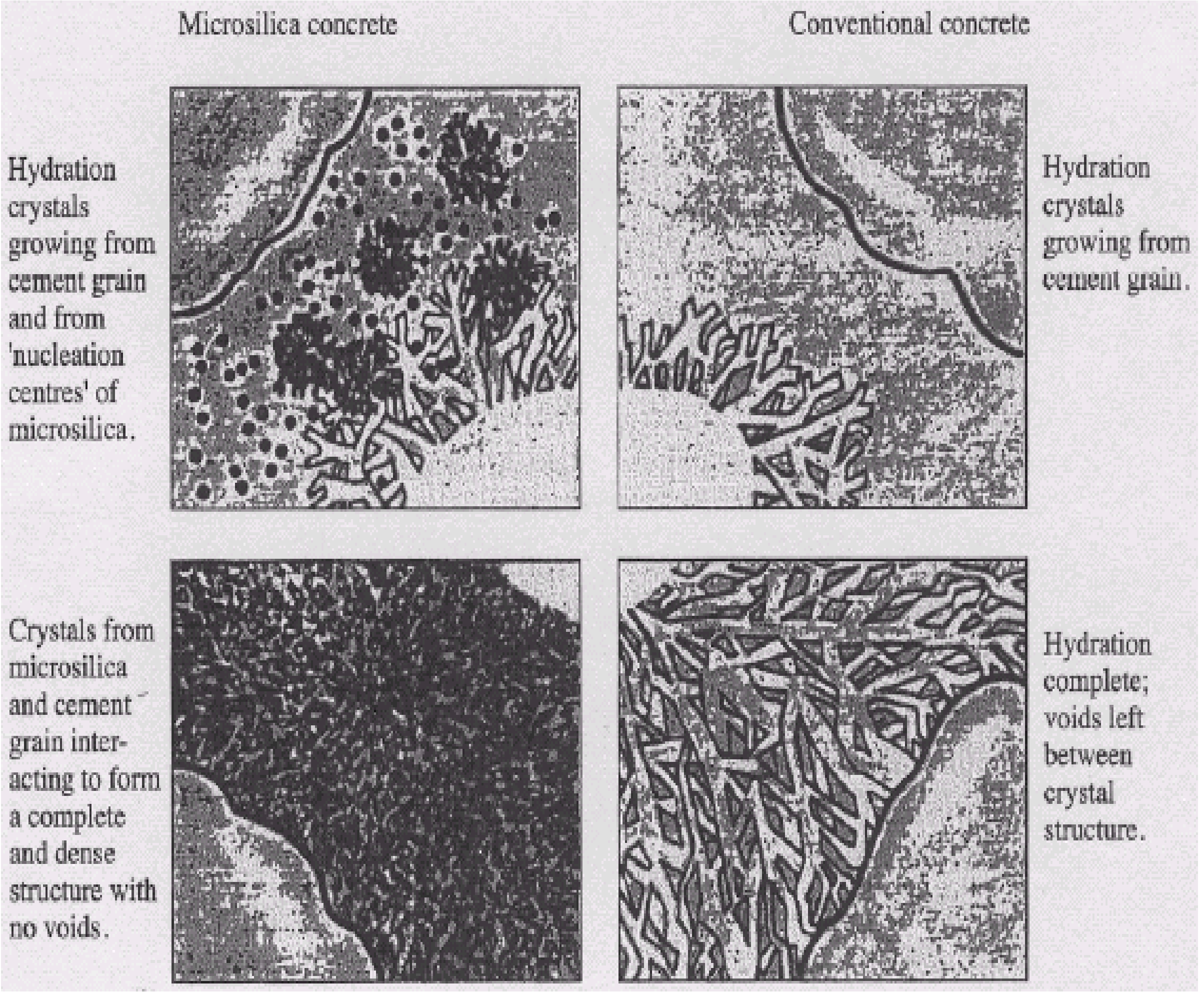

Fig.1.5: Effect of micro-silica in densifying the concrete mix - comparison between conventional and micro-silica concretes (St John, 1998).

Micro-silica is also very effective in reducing both bleeding and segregation. It may contribute to stickiness of a concrete mixture, adjustments, including the use of high-range water reducers, may be required to maintain workability and permit proper compaction and finishing.

The use of silica fume generally aids the pump ability of concrete and is most effective in lean mixtures. Because of its containing silica fume may exhibit an increase in plastic shrinkage cracking (Mindlow et al., 2003) concrete is protected against drying bleeding characteristics, concrete. The problem may be avoided by ensuring that such, both during and after finishing. With proper proportioning and material selection, silica fume can improve the durability of concrete, its resistance to sulphate attack, and the early strength development (Ramachandran, 1984).

Table 1.3: Physical Properties of Silica Fume (khayat,and Aitcin,1987)

Colour	Varies from white or pale-grey to a dark grey
Specific Gravity	It is generally equal to that amorphous silicon which is about 2.2. depending upon its chemical composition the specific gravity of silica fume particle can be as high as 2.4-2.55
Specific Surface Area	About 20000 m^2/kg approximately 10 times more than Portland cement
Particle Size	Mostly fine spheres with a mean diameter of .1 micron
Bulk Loose Density	230-300kg/m^3

Table1.4: Chemical composition of Silica Fume (khayat, and Aitcin, 1987)

Constituents	**Percent**
SiO_2	90-96
Al_2O_3	0.5-0.8
MgO	0.5-1.5
Fe_2O_3	0.2-0.8
CaO	0.1-0.5
Na_2O	0.2-0.7
K_2O	0.4-1.0
C	0.5-1.4
S	0.1-0.4

1.9 Advantages and Disadvantages of Self-Compacting Concrete

Compared to NVC (Normal Vibrated concrete), SCC possesses enhanced qualities, and its use improves productivity and working conditions (De Schutter et al., 2008; The Concrete Society and BRE, 2005).

Because compaction is eliminated, the internal segregation between solid particles and the surrounding liquid is avoided which results in less porous transition zones between paste and aggregate and a more even colour of the concrete (RILEM TC 174 SCC, 2000). Improved strength, durability and finish of SCC can therefore be anticipated. Very good finish effect is shown in Figure 1.7. a pure cement SCC placed in a steel mould, demoulded 24h after casting. The surface is so smooth and dense that it can reflect light.

Figure 1.6: Excellent finish of a neat cement SCC (Okamura and Ouchi, 2003a)

For much concrete construction, the structural performance is improved by increasing reinforcement volumes, limiting cracking by using smaller bar diameters and using complex formwork, all of which increase the difficulty of compaction (Okamura and Ouchi, 2003a; RILEM TC 174 SCC, 2000). SCC meets the above developments by making casting homogeneous concrete in congested structures possible; it also improves efficiency and effectiveness on site by reducing the construction time and labour cost. SCC also improves the workplace environment by reducing noise pollution and eliminating the health problems related to the use of vibration equipment such as 'white fingers' and deafness (RILEM TC 174 SCC, 2000). SCC is therefore called 'the quiet revolution in concrete construction' (The Concrete Society and BRE, 2005).

As a result, the precast concrete products industry has become the biggest user of SCC in Europe. SCC requires higher powder and admixture (particularly super-plasticisers) contents than NVC and so the material cost is higher (The Concrete Society and BRE, 2005). It was reported that in most cases, the cost increase ranged from 20% to 60% compared to similar grade NVC (Nehdi et al., 2004; Ozawa, 2001).

However, in very large structures, increased material cost by using SCC was outweighed by savings in labour costs and construction time. The benefits of SCC were fully displayed in a composite sandwich system, which involves casting SCC and NVC in layers within the same structural elements (Okamura and Ouchi, 2003a; Ouchi, 2001; Ozawa, 2001). The increased content of powder and admixture also leads to higher sensitivity (i.e. reduced robustness) of SCC to material variation than that of NVC; thus greater care with quality control is required.

1.10 Orientation of Thesis Report:

This thesis is presented in five chapters as detailed below:

Chapter-1	Gives the introduction about Self-Compacting Concrete, Fly Ash, and Silica Fume.
Chapter-2	Literature review presents the work done by various researchers in the field of Self- Compacting Concrete.
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

CHAPTER: 2 LITERATURE REVIEW

Present-day self-compacting concrete can be classified as an advanced construction material. As the name suggests, it does not require to be vibrated to achieve full compaction. This offers many benefits and advantages over conventional concrete. These include an improved quality of concrete and reduction of on-site repairs, faster construction times, lower overall costs, facilitation of introduction of automation into concrete construction. An important improvement of health and safety is also achieved through elimination of handling of vibrators and a substantial reduction of environmental noise loading on and around a site. The composition of SCC mixes include substantial proportions of mineral admixtures, which are currently waste products with no practical applications and are costly to dispose of (St John, 1998).

2.1 FLY ASH

2.1.1 Fresh Concrete Properties

Siddique (2010) performed the results of various fresh properties tested by slump flow test (slump flow diameter and T50cm), J-ring test (flow diameter and difference in concrete height inside and outside J-ring (h2–h1)); L-box test (time taken to reach 400 mm distance T400mm, time taken to reach 600 mm distance T600mm, and time taken to reach 800 mm distance TL, ratio of heights at the two edges of L-box (H2/H1));V-funnel test (time taken by concrete to flow through V-funnel after 10 seconds T10s, time taken by concrete to flow through V-funnel after 5 min T5min), U-box test (difference in height of concrete in two chambers (H2–H1)) for various mix compositions are given table 2.1. The slump flow test judges the capability of concrete to deform under its own weight against the friction of the surface with no restraint present. A slump flow value ranging from 500 to 700 mm for a concrete to be self-compacting was suggested At slump flow >700 mm, the concrete might segregate, and at <500 mm, the concrete might have insufficient flow to pass through highly congested reinforcement. All the mixes in the present study conform to the above range since the slump flow of SCC mixes is in the range of 600–700 mm. The slump flow time for the concrete to reach diameter of 500 mm for all the mixes were less than 4.5 sec. The J-ring diameter and difference in concrete height inside and outside J-ring were in the range of 540–625 mm and the difference in height was less than 40 mm. In addition to the slump flow test, V-funnel test was also performed to assess the flow ability and stability of the SCC. V-funnel flow time is the elapsed time in seconds between the opening of the bottom outlet depending upon the time after which opened (T10s and T5min) and the time when the light becomes visible from the bottom, when observed from the top. V-funnel time, which is less than 6 sec., is recommended for concrete to qualify as a SCC. As per EFNARC, time ranging from 6 to 12 sec. is considered adequate for a SCC. The V-funnel flow times were in the range of 4–10 sec. Test results of this investigation indicated that all SCC mixes meet the requirements of allowable flow time. Maximum size of coarse aggregate was kept as 16 mm in order to avoid blocking effect in the L-box. The gap between rebar in L-box test was 35 mm. The L-box ratio H2/H1 for the mixes was above 0.8 which is as per EFNARC standards. U-box difference in height of concrete in two compartments was in the range of 5–40 mm.

Table: 2.1: Fresh properties of SCC mix. (Siddique, 2010)

Mix	**Slump Flow**		**j-Ring**		**V-funnel**		**L-Box**				**U-box**
	Dia. (mm)	T50cm (s)	Dia (mm)	h2–h1 (mm)	T10s (s)	T5min (s)	T400mm (s)	T600mm (s)	TL (s)	(H2/H1)	(H1–H2) (mm)
SCC1	673.3	4.5	586.7	2.3	7.5	15.0	3.5	8.3	11.9	0.89	20
SCC2	690.0	3.0	580.0	6.7	4.5	5.1	1.4	2.4	3.5	0.95	10
SCC3	603.3	4.4	540.3	37.0	5.2	7.6	0.5	1.3	2.4	0.85	40
SCC4	673.3	3.0	626.7	3.0	6.1	9.5	1.2	2.2	4.0	0.95	5
SCC5	633.3	4.0	556.3	7.0	10.0	18.5	2.8	4.8	6.9	0.92	20

Liu (2010) studied that Due to its spherical shape, fly ash can disperse agglomeration of cement particles. When cement is replaced by fly ash, a lower dosage of super plasticiser and an increased quantity of water is therefore required to maintain the same filling ability passing ability is dependent on coarse aggregate content and viscosity. The step height of the J-ring test, which gives an indication of the passing ability increased from 11 mm (F0) to 22 mm (F100) for SCC with cement only and with fly ash only respectively. The difference of 11 mm is higher than the typical within-test variation of 8 mm reported by Bartos. If the difference does not come from variation of the test method itself, it should result from the difference between two mixes. F100 has a higher W/P ratio and a lower super plasticiser dosage than F0. The combined influences of an increase in fly ash content and W/P ratio and a decrease in super plasticiser dosage lead to the increased viscosity and hence the increase in step height as the coarse aggregate content is constant. There is an improvement in segregation resistance for the SCC mixes incorporating 80% and 100% fly ash. The segregation index of these mixes is only 5–7% which is low. This is in line with the results from Bouzoubaa and Lachemi that for SCCs with fly ash, segregation index decreased with an increase in fly ash which accompanied an increase in the super plasticiser content and a decrease in the W/P ratio. The other study showed that segregation resistance was related to the passing ability and viscosity of SCC. As stated above, these mixes have higher viscosity than those incorporating up to 60% fly ash. This can result in lower segregation. To assess the consistence retention, the slump flow and the V-funnel time measured at 65 ± 5 min after addition of the water that after about an hour, slump flow decreases and v-funnel time increases, which means that the filling ability decreases with time. They should behave the same in all fresh concrete properties. However, the results of step height in the J-ring test, the sieve segregation, and the slump flow and the v-funnel time 65 min after mixing clearly showed that target SCC's did not have the same passing ability, segregation resistance and consistence retention.

Sukumar et al.(2008) conducted workability tests such as slump flow test, V-funnel test, L-box test and GTM screen stability test as per specifications were carried out to test the flow ability, filling ability, passing ability and segregation resistance as per specifications. The workability test results Table 2.2. found to be within the prescribed limits as per specifications and guidelines and satisfy all the required rheological characteristics and self-compactability.

Table: 2.2: Workability test results with recommended limits (Sukumar et al.2008)

Mix ID	w/p ratio	SP/b ratio	Slump Flow(mm)	T_{50cm} slump flow(s)	V-funnel flow T_f	V-funnel at T_{min}	L-box T_{20},T_{40}(s)	L-box h2/hi	GTM segregation ratio
AS30	0.34	0.4	793	1.0	3	4	1.0, 1.5	1.0	3
BS30	0.33	0.4	675	1.5	5	6	2.0, 2.5	0.91	10.2
AS40	0.33	0.4	786	1.0	4	5	1.0, 1.5	0.99	4.2
BS40	0.33	0.4	690	2.0	5	5	2.0, 2.5	0.92	9.8
AS50	0.32	0.5	773	1.5	4	5	1.5, 2.0	0.96	5.5
BS50	0.32	0.5	685	2.0	4	5	1.5,2.0	0.89	8.5
AS60	0.32	0.6	766	1.5	5	6	1.5, 2.0	0.95	6.2
BS60	0.31	0.6	695	2.0	4	5	1.5, 2.0	0.94	9.5
AS70	0.31	0.7	742	2.0	5	6	1.5, 2.0	0.95	6.8
BS70	0.31	0.7	680	2.0	4	6	1.5,2.0	0.90	8.2
Recommendation limits			**600-800**	**<3**	**<6**	**<T_f+3**	**1-2.5**	**>0.8**	**<15**

w/p, water/powder (cement + fly ash + filler); SP/b, super plasticiser/binder (cement + fly ash).

Khatib (2008) investigated on total 8 mixes that were employed to examine the properties of self-compacting concrete (SCC) with and without fly ash (FA). Details of mixes are given in Table 2.8. The constituents of mixes were Portland cement (PC), fly ash (FA), water, fine aggregate and coarse aggregate. The PC and FA complied with EN 197-1 and EN 450, respectively. The fine aggregate used conformed to class M of BS 882: 1992, and 10 mm nominal size crushed and washed was used as coarse aggregate. The only admixture (AD) used to produce self-compacting concrete was a liquid based on a modified synthetic carboxylated polymer. The AD conformed to Types A and F Admixtures of BS 5075 Parts 1 & 3 and EN 934-2:2000 with a relative density of 1.08.

All mixes exhibited high workability, in that the flow spread (i.e. diameter) for all mixes is in excess of 700 mm except for the control mix M1 where a spread of 635 mm is obtained where a relatively low dosage of AD is added. These values are higher than those indicating elsewhere. Slump flow of 650 ± 50 mm is required for SCC, and all the mixes under investigation fall in this category. Visual examination of mixes containing FA suggest that there is further increase in workability, as demonstrated by the ease of flow in the moulds, compared with the control at the same dosage of admixtures (i.e. 0.7%). It is well established that the use of FA in concrete reduces the water demand for a given workability. Therefore, concrete containing FA will cause an increase in workability at constant water to binder ratio.

Yazıcı (2007) Conducted workability tests it can be seen from the Table 2.3. slump flow diameters vary between 710 mm and 825 mm. It is well known that T50 and V-box times may be accepted as a measure of plastic viscosity, slump flow diameter indicates the yield stress. T50 times increase with the increasing FA content in H series. Whereas in HS series, which contain 10% SF as a cement replacement, the increase in FA content lowered the plastic viscosity of mixes while maintaining the flow values approximately equal. In other words incorporation of FA and SF increased the super plasticizer demand. This is probably due to the increasing paste volume with FA and SF since the specific gravities of these mineral additives are lower than cement. Besides, when FA is incorporated in the mixture, increase in the amount of admixture may be required due to the increasing carbon content. Furthermore the other factor may be the effect of SF and FA on the cohesion of the fresh concrete. Generally, similar workability properties were obtained at all mixes in fresh state except H50 and H60 mixtures.

Table.2.3: Properties of fresh concrete (Yazıcı, 2007)

Series	**FA %**	**Flow(mm)**	**T50**	**V-box**	**Air Temp. .**
C	0	710	3.5	20	30
H30	30	785	3.5	18	25
H40	40	750	4.5	23	27
H50	50	800	5	42	24
H60	60	780	7.5	35	28

Domone (2006) conducted slump flow test, which measures the flow capacity, has been universally used, and hence values of slump flow spread. Nearly 50% of the applications used values in the range 650–700 mm, with nearly 90% in the range 600–750 mm. Flow rate values, expressed either as T500, V-funnel or Orimet times were reported in about half of the case studies. They varied considerably; T500 times ranged from 1.8 to more than 12 sec. and V-funnel or O-funnel times from 3 to 15 sec. there is thus a wide range in this property. There was no pattern of higher slump flows being associated with lower flow rate values, indicating the independence of these properties, and the ability to design mixtures with a combination thought suitable for a given application. L box blocking ratio values were all in excess of 0.8; U-box values were in excess of 300 mm, with the reinforcement spacing varied in some cases to suit the application.

Pereira-de-oliveira et al. (2005) evaluated slump flow, L box, V funnel test to get the SCC workability. The characteristics and properties of mixtures are presented in the Table 2.4. being used, in accordance with the addition material used, abbreviations. SCCFA for self-compacting concrete with fly ash.

Table 2.4: Proportion in mass of the component materials of the tested mixtures (Pereira-de-oliveira et al. 2005)

Ingredients	**NC**	**SCCFA**
Cement (Kg)	100	100
Fly Ash (Kg)	-	15
Sand (kg)*2.8	88	126
Sand (kg)*4.5	88	126
Aggregates (6-15) kg	275	198
Water/cement (kg/kg)	0.40	.40
Super-plasticizer Viscocrete 3000	1.50	2.5
Water/powder material	0.40	0.35

*fineness module

Table 2.5. Present the results of tests carried out to verify the self-compacting of concrete. The results of slump-flow test carried out in SCC concrete characterize the mixtures as being self compacting. However, the mixture SCCSF presents relationships H_1/H_0 below 0.80. This value has been recommended as minimum value for this test that simulates the capacity of concrete transit inside the formwork and it depends on the steel bars density contained.

Table 2.5: Results of Slump-flow, L box and V funnel tests (Pereira-de-oliveira et al., 2005)

		NC	SCCFA
Slump	(mm)	35	-
Slump	Time (seg.)	-	4.81
Flow	Final average	-	650
L box	T_{40}(seg.)	-	5’46”
	H_1/H_0(cm)	-	0.86
V-funnel	Time (seg.)	-	10’00”

Xie et.al (2000) reported the optimum mix parameters of high strength self –compacting concrete with ultra pulverized fly ash. All the materials used in this research were locally available. In this research cement was replaced by 30% of ultra pulverized fly ash of total cementitious material and sand was replaced by broken gravels. Super-plasticizer content is 1.0-1.6 % of total cementitious material for water content of 175 l/m^3.When the super-plasticizer content is higher than 1.9% compressive strength decreases because of bleeding. The results of this research indicates that higher the sand ratio, better the workability of fresh SCC, and smaller the compressive strength difference between SCC and normal concrete and the sand ratio cannot be less than 40%.

2.1.2 Hardened Concrete Properties

Compressive strength

Siddique (2010) investigated the compressive strength tests results of SCC mixes are given in Table 2.6. and Fig. 2.1. With the increase in fly ash content from 15–35%, SCC mixes developed compressive strengths between 29.5 and 22.8 MPa at 7 day; between 35.2 and 29.6 at 28 day; between 58.9 and 40.8 at 90 day; and between 61.2 and 43.7 MPa at 365 day. The compressive increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio. An increase of about 18% strength at 28 days and 40% at 365 days was observed with the decrease of fly ash content from 35% (SCC1) to 15% (SCC5). The strength values at 7 days of SCC5 (35% fly ash) are comparable with the results for the replacements with fly ash at 40% of total powder content. But strength at 28 days was found to be lower since no VMA and AEA was added to the SCC mixes. It was observed that the strength gain at 90 days and 365 days was within the limits corresponding to the amount of cement content used in the SCC mixes. For the same mix, the strength values corresponded to those at 28 days age of curing. SCC4 (30% fly ash) attained strength of 23.98 MPa, 30.66 MPa, 41.96 MPa and 44.84 MPa at 7, 28, 90, and 365 days, respectively. Similarly, SCC 3 (25% fly ash) attained strength corresponding to 25.52 MPa, 31.47 MPa, 43.77 MPa and 46.47 MPa, at 7, 28, 90, and 365 days, respectively. For the SCC 2 (20% fly ash) mix at 19% cement replacement by fly ash in total powder content. The strength of SCC 2 (20% fly ash) in the study at 28 days was 33.15 MPa whereas at 90 days was 52.86 MPa which was much higher content in the mix.

Table.2.6: Compressive and splitting tensile strength of SCC mixes. (Siddique, 2010)

Mix	**Compressive strength (MPa)**				**Splitting tensile strength (MPa)**		
	7days	28days	90days	365days	28days	90days	365days
SCC1	29.55	35.19	58.99	61.24	2.40	2.68	2.96
SCC2	27.99	33.15	52.86	54.60	2.12	2.33	2.61
SCC3	25.52	31.47	43.76	46.67	1.83	2.12	2.33
SCC4	23.98	30.66	41.96	44.87	1.76	1.97	2.26
SCC5	22.78	29.62	40.88	43.73	1.55	1.76	2.12

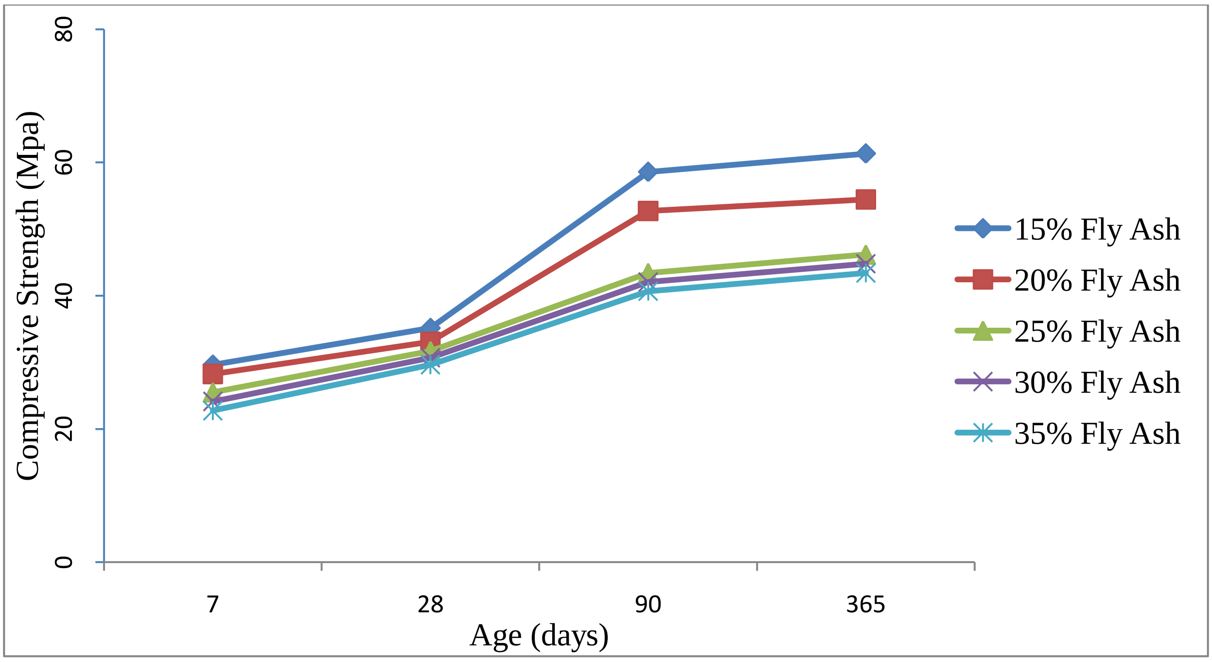

Fig.2.1: Compressive strength of SCC mixes at various ages. (Siddique, 2010)

Miao Liu (2010) studies that there is little difference in the compressive strength, splitting strength between the control (F0) and 20% replacement (F20) mixes, which shows that the use of 20% fly ash did not significantly change the hardened concrete properties. However, there is a significant decrease in strength at all ages when the cement replacement ratio is more than 40%. The influence of fly ash on strength was more significant at higher contents. The value of SCC with 80% fly ash was only one quarter of that with 20%.This is attributed to the slower Pozzolanic reaction of the fly ash with the Ca $(OH)_2$ of the hydrated cement. Thus the higher the replacement level of fly ash in concrete, the higher the reduction in the hardened properties since not enough cement hydration products react with fly ash. The higher W/P ratios by weight also contribute to the reduction. These results are found to be in line with published data .HVFA SCC with 80% fly ash has the lowest values of all hardened properties. It however gained enough strength to be de-moulded after placed at room temperature for 24 h after mixing. Although it's compressive strength is only 13% of the control SCC at 7 days, significantly lagging the control, it gained strength at late ages, achieving 22% and 33% of the control mix at 28 days and 90 days respectively. This SCC can be used in non-structural applications, where early strength is not required and ultimate strengths are in the range of 25–35 MPa, such as mass concrete.

Turk et al. (2010) Compressive strength results of NC and SCC specimens with FA for 3, 28 and 130 days are presented in Fig. 2.2. It can be observed that all SCC specimens had higher compressive strength, compared to NC specimens. SCC with followed by FA25 with 27.66 MPa for 3 days However, the compressive strength of SCC specimens decreased with an increase in

FA content for 3 days. On the other hand, when it was considered only SCC specimens with FA, FA25 had the highest compressive strength with 27.66 and 49.39 MPa at 3 and 28 days, respectively, whilst FA40 had the highest compressive strength with 58.11 MPa followed by FA35, FA30, FA25 and NC at the periods of 130 days. Finally, there was in general an increase in the compressive strength values of SCC specimens with increase in FA content for periods of 130 days. This increase in strength can be attributed the densification of the paste structure due to the pozzolanic action.

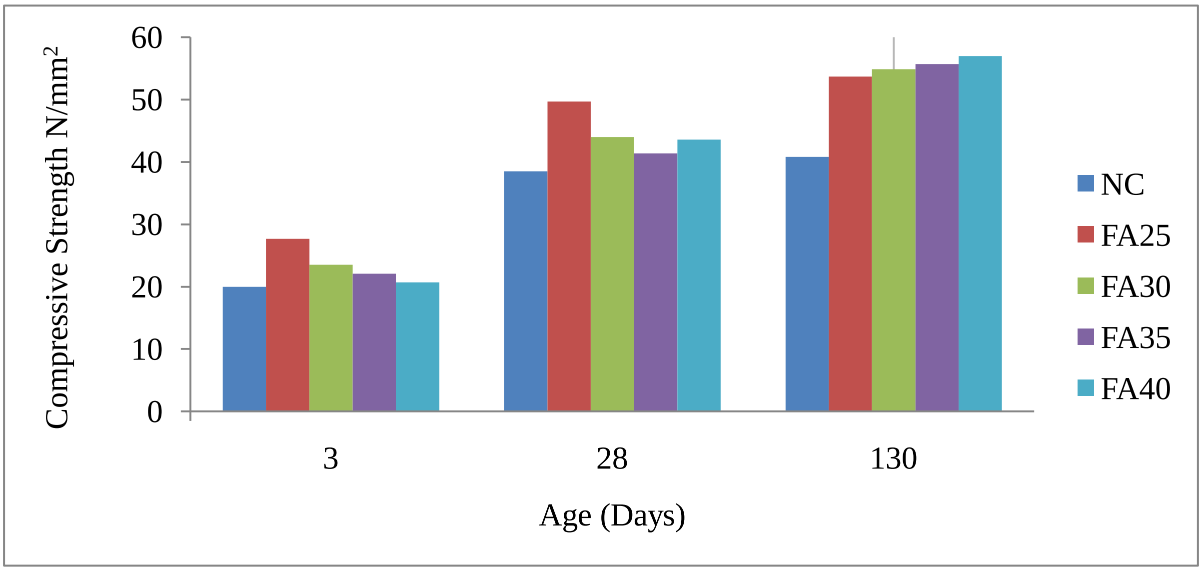

Figure 2.2: Compressive strength of NC and SCC specimens for 3, 28 and 130 days. (Turk et al., 2010)

Dinakar et al. (2008) studied that 20 MPa grade concrete, self compacting fly ash concrete at 85% replacement of fly ash (SCC558) showed lower strengths at all ages compared to normal concrete. However, SCC558 reached its design strength at 90 days. In 30 MPa concretes even at 70% replacement the strength gain rate of SCC was almost similar to that of normal concrete. At the 70% replacement level, both the self compacting fly ash concretes obtained their designed target strength of 30 MPa at 28 days and both were performing similarly. However, at 180 days, the strengths obtained for SCCs were greater than the normal vibrated concrete. The strength development of normal vibrated concrete almost came to a complete stop after 90 days, whereas the SCCs continued to gain strengths even after 90 days. In 60 MPa grade concrete, both the self compacting fly ash concretes achieved their design strengths at 90 days. Normal concrete had shown slightly higher strengths at all ages. At 180 days the strengths of both normal vibrated concrete and SCCs were comparable. In the case of high strength normal vibrated and self compacting fly ash concretes of 90 MPa and 100 MPa, it can be noticed that the normal vibrated concretes, even at 180 days, have not achieved their design strengths and the strength gain rate is comparatively low after 28 days for 90 MPa concrete whereas it was low from 7 days in case of 100 MPa concrete. But in the case of self compacting fly ash concretes the results indicate that there was continuous and significant improvement in strength beyond the age of 28 days. It was also observed that both the self compacting fly ash concretes designed for 90 and 100 MPa achieved their design strengths at 180 days.

Khatib (2008) investigated the effect of different dosages of AD on concrete strength for the control mixes (M1–M3) is shown in Fig. 2.3. Using either a relatively low or high dosage of AD reduces the strength, whereas using an optimum dose of AD (e.g. 0.7%) causes an increase in strength. As suggested earlier, low dosage might lead to the creation of pore if concrete is to be compacted under its own self-weight only, whereas high dosage might lead to segregation. This can justify the relatively high strength obtained when a medium dose of AD (0.7%) is added to the concrete. Fig. 2.4. shows the influence of FA incorporation on concrete strength at a constant addition of AD (0.7%). Concrete containing 40% FA shows higher 56 days strength than the other FA mixes including the 20% FA mix, whereas high strength of approximately 70 N/mm^2 at 56 days is obtained. Generally and at the same water to binder ratio, there is strength reduction for concretes containing FA compared with that of the control. However, and even at high FA content (60%), a long-term high strength of about 40 N/mm^2 is achieved at the same water to binder ratio. Higher strength would be expected in FA mixes if the w/b ratio was lowered to achieve similar workability to that of the control.

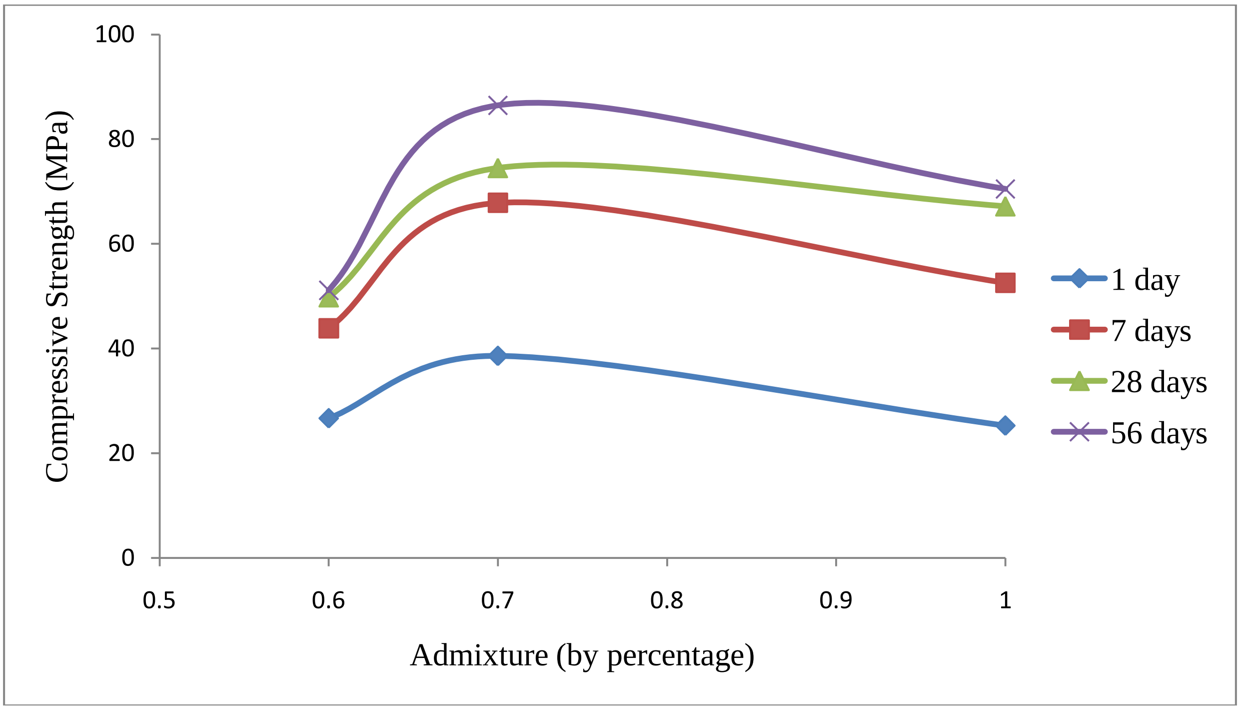

Fig.2.3: Influence of admixture dosage on strength. (Khatib,2008)

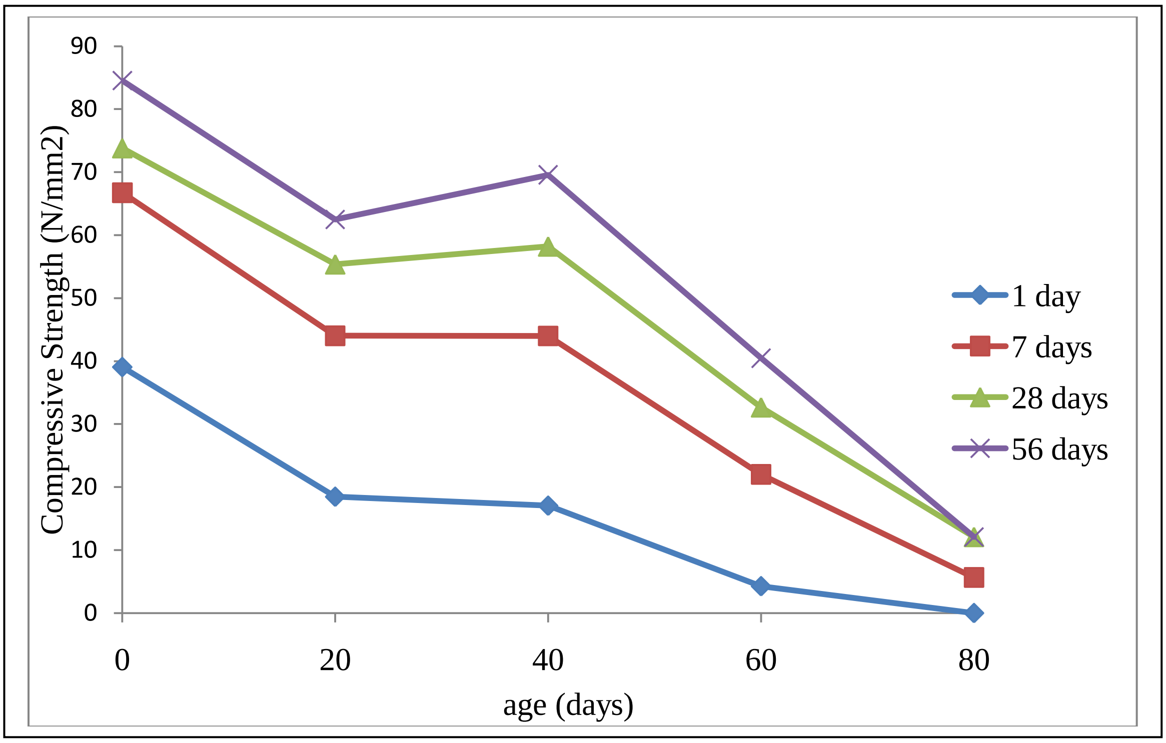

Fig.2.4: Influence of FA content on strength (AD = 0.7%). (Khatib, 2008)

Yazıcı (2007) conducted test of compressive strength development of H series within time is presented in Fig. 2.5. The results show that the compressive strength decreases with the increasing FA content at all ages. It can be seen from Fig. 2.5 that, the compressive strength of control (0% FA) and 60% FA mixtures were 61.8 MPa and 28.4 MPa, respectively at 28 days. All mixes show strength gain beyond 28 days and the control mixture reached to 72.5 MPa at 90 days while this value was 38 MPa for 60% FA content. However, it is clear that, it is possible to produce a SCC with a compressive strength value of 50 MPa with 30–40% FA replacement.

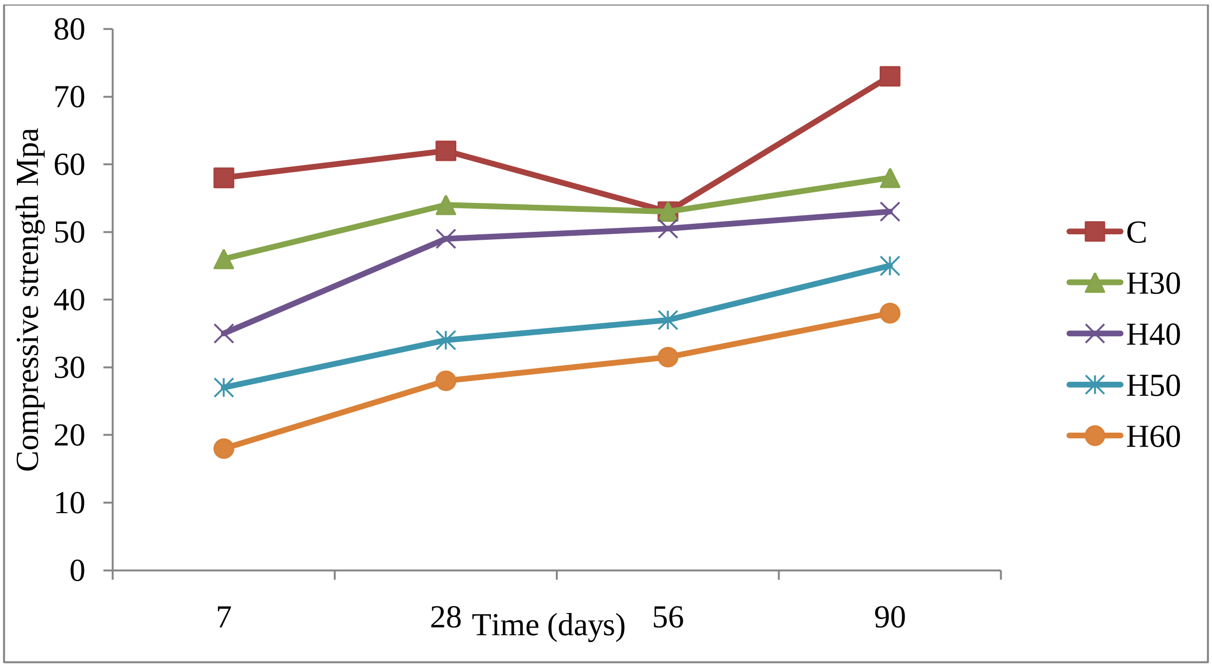

Fig.2.5: Relation between fly ash content and compressive strength (Yazıcı ,2007)

Domone (2006) studied the 28 day strength values were reported in nearly all cases. Values ranged from 20 to nearly 100 MPa, with about 80% of mixes having strengths in excess of 40MPa it is possible to produce SCC with strengths to suit nearly all normal concreting situations. Strengths are controlled mainly by the binder composition, and not with water/binder ratio as in conventional workability concrete.

Splitting Tensile Strength

Siddique (2010) conducted test on Splitting tensile strength, test results of SCC mixes are shown in Fig. 2.6. SCC mixes achieved splitting tensile strength from 1.55 to 2.40, 1.76 to 2.68, and 2.12 to 2.96 MPa at 28, 90 and 365 days, with the increase in fly ash content from 15 to 35%. Splitting tensile strength increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio. With the increase in cement content, the strength of SCC1 (15% fly ash) gradually increased to 2.40 MPa at 28 days. An increase of about 54% of strength at 28 days and 40% at 365 days as observed with the decrease of the fly ash contents from 35% (SCC5) to 15% (SCC1). SCC4 (30% fly ash) attained strength 1.76 MPa, 1.97 MPa, and 2.26 MPa at 28, 90 and 365 days, respectively. Similarly, SCC3 (25% fly ash) attained strength corresponding to 1.83 MPa, 2.12 MPa and 2.33 MPa, at 28, 90 and 365 days, respectively. As the percentage of fly ash in mixes decreased, the tensile strength increased at all ages. The value of split tensile strength was reported as 2.82 MPa at 28 days.

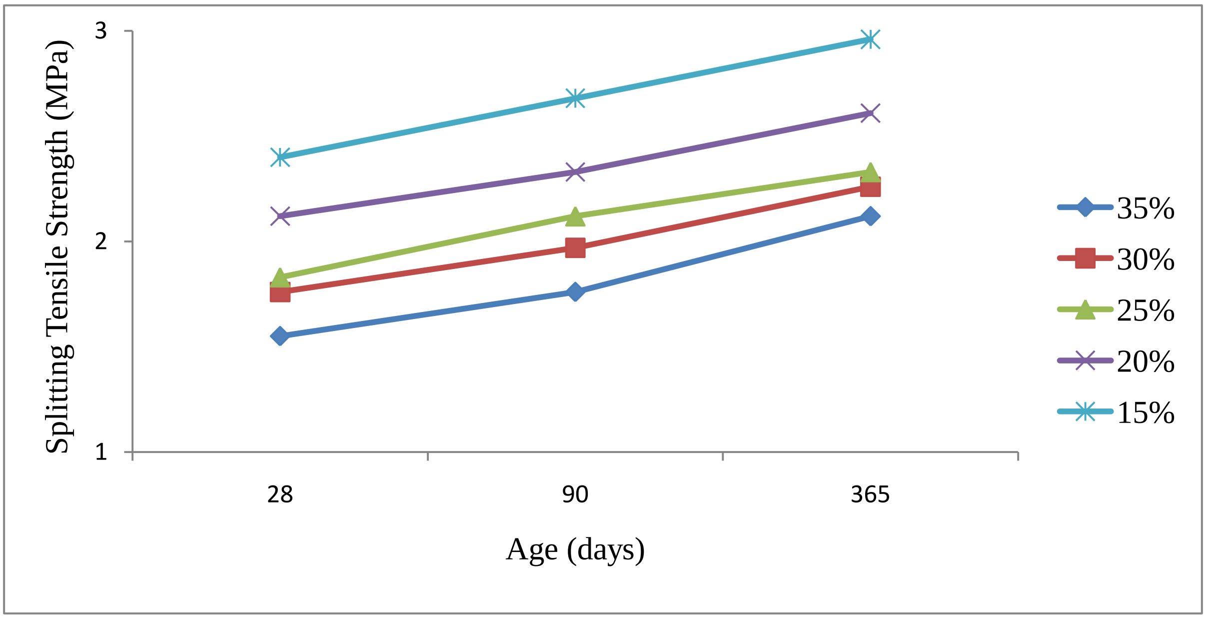

Fig.2.6: Splitting tensile strength of SCC mixes at various ages. (Siddique, 2010)

Turk et al. (2010) studied that test results of the splitting tensile strength of NC and SCC specimens with FA are shown in Fig. 2.7. The splitting tensile strength of SCC specimens with FA and NC specimens for all curing ages. At curing ages of 3 days, the splitting tensile strength of SCC specimens with FA decreased the splitting tensile strength of SCC specimens increased when FA content in mixture increased. There was no significant difference between the values of the splitting tensile strength of SCC specimen with FA for 28 and 130 days when they were considered separately. At the curing ages of 130 days, an increase in FA in general led to an increase in the splitting tensile strength. Furthermore, difference between the values of the splitting tensile strength of SCC and NC specimens increased at the curing ages of 130 days. These may be attributed to the pozzolanic reaction for forming C-S-H gel. On the other hand, it can be seen that the increase in compressive strength will be more than that of tensile strength when FA content increased. This may be explained with the effect of the unreacted FA particles on the tensile properties as the bond between aggregate and the blended paste will more be affected by the splitting tensile test.

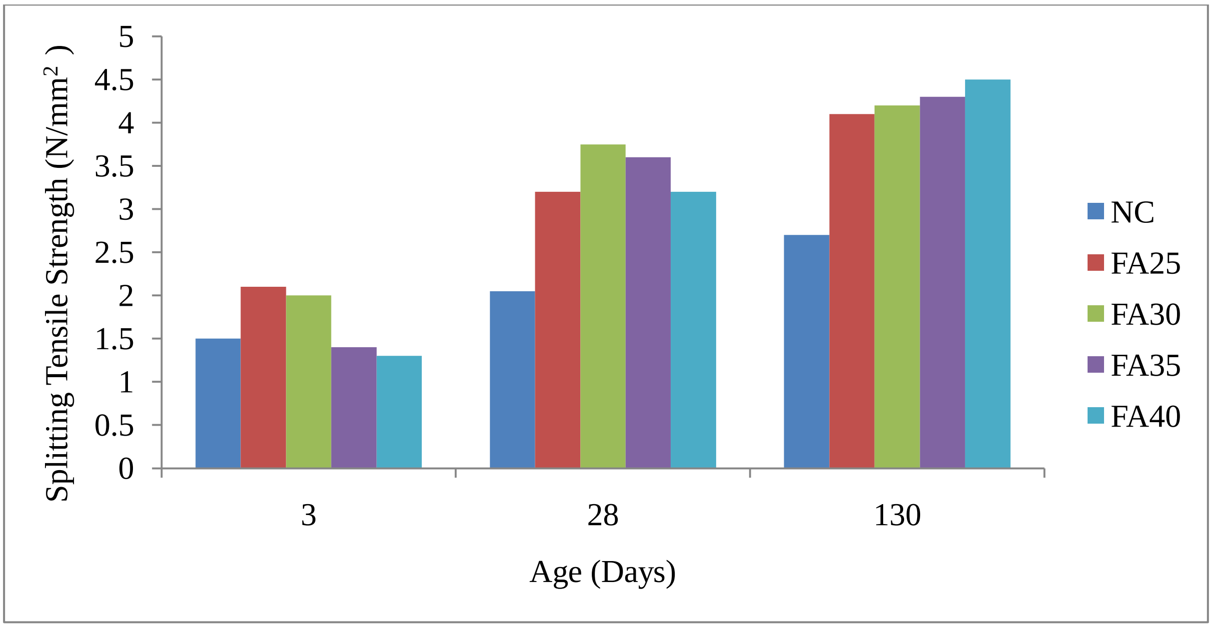

Figure 2.7: Splitting tensile strength of NC and SCC specimens for 3, 28 and 130 days. (Turk et al., 2010)

Sahmaran et al. (2009) studied the results of split tensile strength tests at 28, 90 and 180 days. The split tensile strength ranges from 3.21 to 5.07 MPa, 3.64 to 5.14 MPa and 4.19 to 5.64 MPa at 28, 90 and 180 days, respectively. The split tensile strength of all SCC mixtures increased with age. The results showed that, an increase in the FA content decreased the split tensile strength of the SCC especially at 28 days. SCC mixtures containing 30–50% FA replacement showed higher split tensile strength than SCC mixtures containing 60–70% FA replacement. This indicates that up to a 50% of FA replacement may have positive effects on the interfacial bond between the paste and aggregates. The mixtures containing 60–70% FA showed lower tensile strength probably due to the weaker bond between the matrix and the aggregates.

Yazıcı (2007) studied that with increasing amount of FA content over 30%, splitting tensile strength decreased for H series. Although there is slight reduction in splitting tensile strength at 40% and 50% FA content compared to the control mixture, splitting tensile strength of FA60 mixture is almost equal to the control mixture for HS(FA %) series.

2.1.3 Rapid Chloride Permeability

Siddique (2010) reported that the use of fly ash decreased the rapid chloride penetration Coulomb value of concrete and the presence of fly ash could improve the permeability of concrete due to its capability of transforming large pores of concrete into small pores and reducing micro cracking in the transition zone. The reduction of chloride migration due to presence of fly ash can be explained partially by the fact that spherical particles of fly ash could improve the particle density in the matrix and the interface zone between aggregates and paste. Rapid chloride permeability test results of SCC mixes are given in Table.2.7 and shown in Fig.2.8. It is evident from these results that all SCC mixes made with fly ash reduced the rapid chloride ion penetrability to the very low range (less than 400 and 700 Coulomb) at the age of 90 and 365 days respectively. The incorporation of fly ash resulted in a reduction in Coulomb charges. The Coulomb charge of SCC 5 (35% fly ash) was 310 Coulomb at 365 days, indicating high chloride penetration resistance. In the study, the charge in the mixes varied with the increase in fly ash content. For SCC 3 (25% fly ash) penetration is least. With the increase in fly ash content above 30%, decrease in chloride penetration was observed.

Table 2.7: Charge passed and rating for SCC mixes (Siddique, 2010)

Mix	**90 days**		**365 days**	
	Charge pass in colombs	Chloride ion permeability	Charge pass in colombs	Chloride ion permeability
SCC1	662	Very low	381	Very low
SCC2	649	Very low	373	Very low
SCC3	594	Very low	303	Very low
SCC4	634	Very low	350	Very low
SCC5	610	Very low	310	Very low

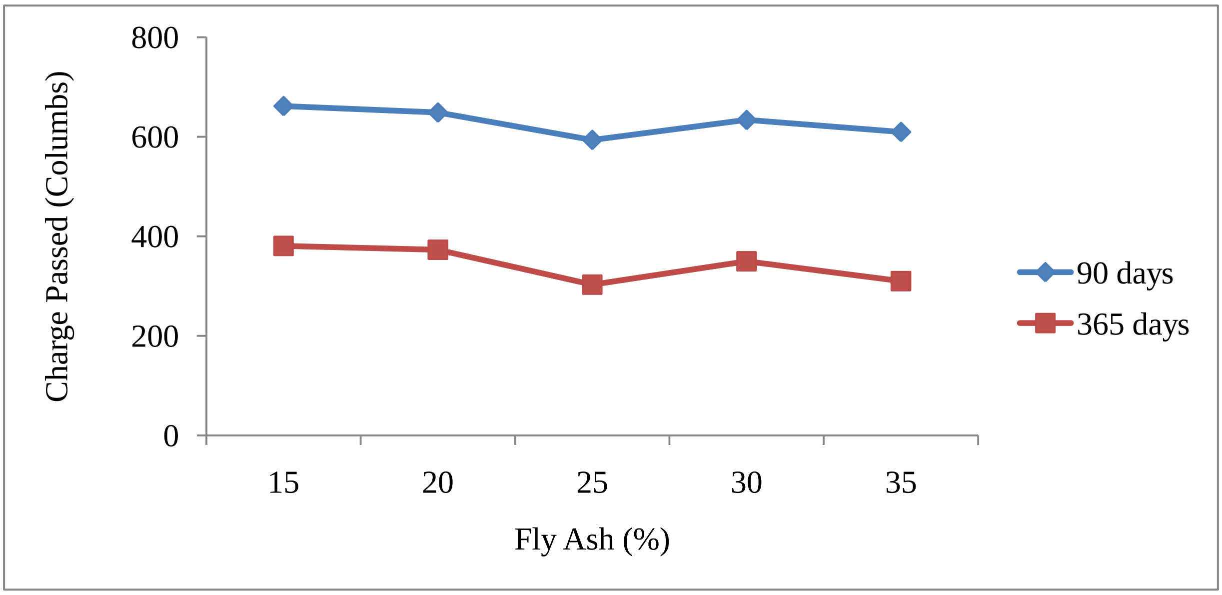

Fig.2.8: Chloride penetration for SCC mixes at various fly ash content. (Siddique, 2010)

Dinakar et al.(2008) studied that (except 20 MPa SCC) all self compacting fly ash concretes showed less than 1000 Coulombs total charge passing and these were assessed as ‘‘very low” chloride permeability concretes as per ASTM C 1202–94 assessment criteria. The corresponding normal concretes showed values in the range ‘low’ to ‘moderate’ according to the assessment criteria. The chloride diffusion values obtained for self compacting concretes of grades 20, 30 and 60 MPa, which had high volumes of fly ash (85, 70 and 50%), were about 2 to 8 times less than the corresponding normal vibrated concretes. The higher grades 90 and 100 MPa which had fly ash replacements at 30 and 10% performed almost similar to normal vibrated concretes. This clearly indicates that the high volume fly ash self compacting concrete mixes performed much better with respect to chloride penetrability.

2.2 SILICA FUME

2.2.1 Fresh and Hardened Properties

Turk et al. (2010) studied the fresh concrete properties of the four different concretes are summarized in Table 2.8. The results obtained from these tests showed that all SCC mixes had good flow, filling and passing ability as well as segregation resistance (see Table 2.8). All conventional concrete specimens were cast on a vibrating table to ensure optimum compaction, whilst the SCC

Table.2.8: Properties of fresh concretes (Turk et al., 2010)

Mixture	**SCC with SF**			
Slump (mm)	701	701	708	707
$T_{50cm\ (s)}$	2.30	1.8	1.2	1.0
L-Box	0.87	0.87	0.88	0.89
Seg. (%)	15.3	17.9	19.8	22.0

Compressive strength results of NC and SCC specimens with SF for 3, 28 and 130 days are presented in Fig. 2.9. It can be observed that all SCC specimens had higher compressive strength, compared to NC specimens. SCC with SF5 had the highest compressive strength with 36.15 MPa for 3 days indicating that SF due to its highly reactive nature may provide significant amounts of calcium silicate hydrates (C-S-H) at an early age. However, the compressive strength of SCC specimens decreased with an increase in SF content for 3 days. Moreover, the highest compressive strength was obtained from the specimens of SCC with SF in all mixes investigated for all curing ages whilst SCC with SF15 had the highest compressive strength with 67.95 and 73.87 MPa for 28 days and 130 days, respectively. Hereby, it can be said that as silica fume is a very reactive Pozzolans and appears to be effective filler, the enhancing effect of SF on concrete compressive strength is due to its ability to improve the bond between the aggregate particles and the paste phase.

Test results of the splitting tensile strength of NC and SCC specimens with SF are shown in Fig. 2.10. The splitting tensile strength of SCC specimens with SF was the highest followed by SCC specimens with FA and NC specimens for all curing ages. At curing ages of 3 days, the splitting tensile strength of SCC specimens with SF in general increased when SF content in mixture increased. There was no significant difference between the values of the splitting tensile strength of SCC specimens with SF for 28 and 130 days when they were considered separately. At the curing ages of 130 days, an increase in SF in general led to an increase in the splitting tensile strength. Furthermore, difference between the values of the splitting tensile strength of SCC and NC specimens increased at the curing ages of 130 days. These may be attributed to the pozzolanic reaction for forming C-S-H gel. On the other hand, it can be seen that the increase in compressive strength will be more than that of tensile strength when SF content increased. This may be explained with the effect of the unreacted SF particles on the tensile properties as the bond between aggregate and the blended paste will more be affected by the splitting tensile test

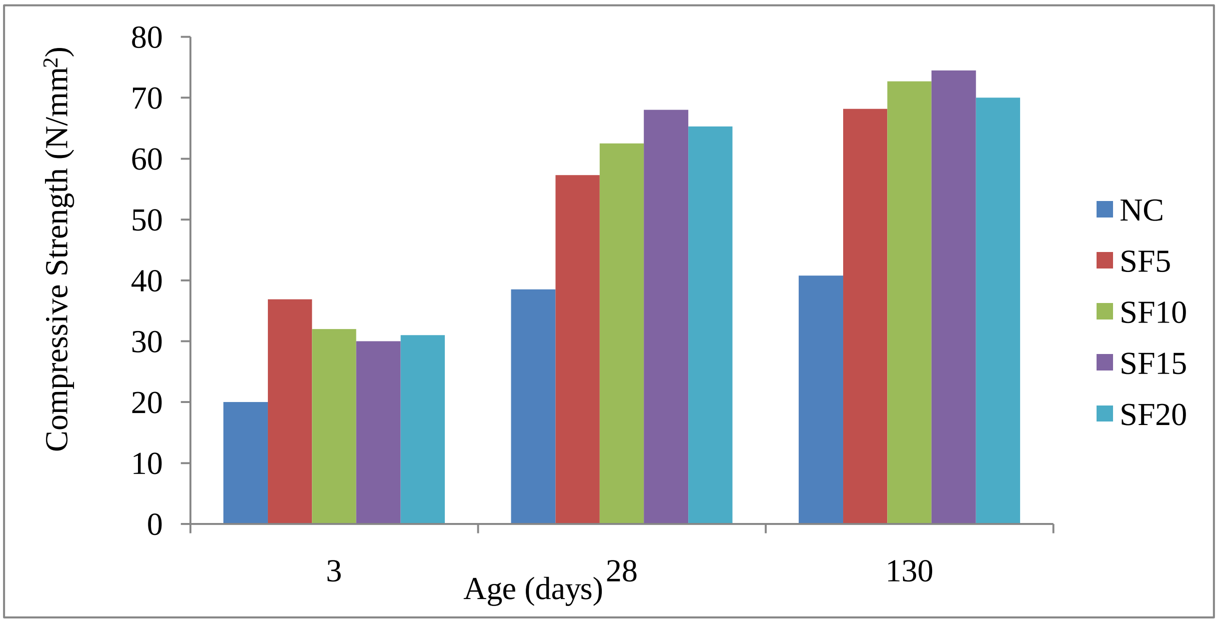

Figure 2.9: Compressive strength of NC and SCC specimens for 3, 28 and 130 days. (Turk et al., 2010)

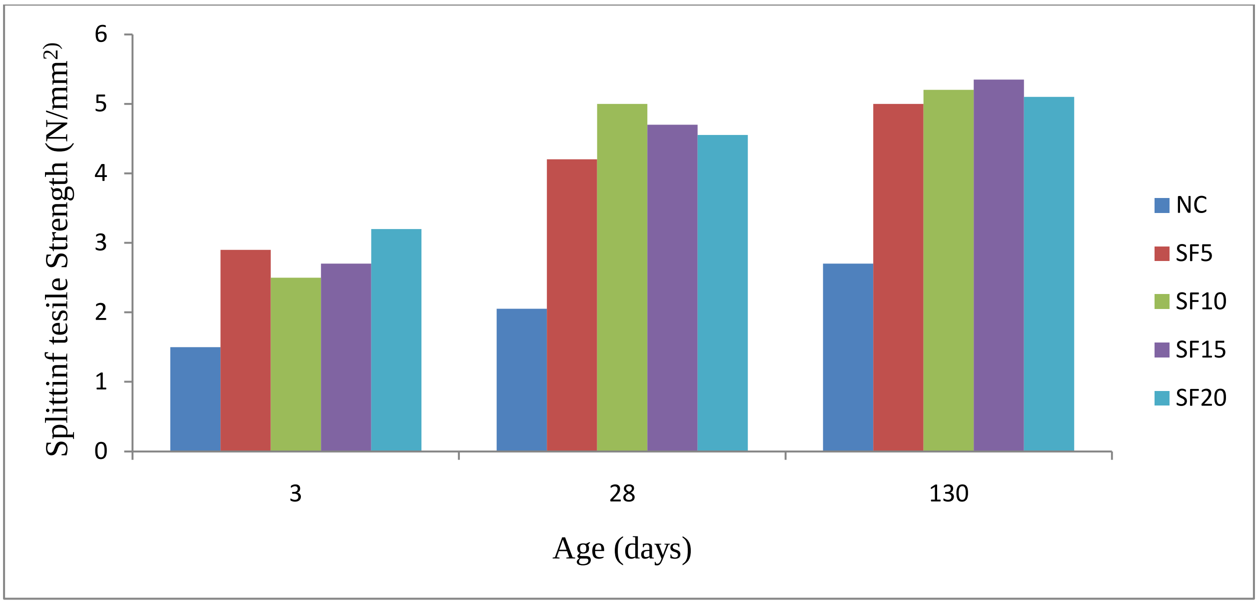

Figure 2.10: Splitting tensile strength of NC and SCC specimens for 3, 28 and 130 days. (Turk et al., 2010)

Turk et al. (2007) for his study, three concrete types were selected, namely PC concrete, SCC silica fume was used as cement component in SCC. While the PC concrete contained combination of PC/SF (90/10%). Details of concrete mix compositions and properties of fresh concretes are given in Table 2.9 and Table 2.10 respectively.

Table 2.9: Mix proportions of concretes used (Turk et al., 2007)

Mix	Cement (kg/m^3)	SF (kg/m^3)	W/B	Sand (kg/m^3)	Aggregates (kg/m^3)		SP (1/m^3)
					5-10	10-20	
PC	310	-	0.58	680	520	720	-
SCCC	400	40	0.37	1090	470	335	8.4

Table 2.10: Properties of fresh concretes (Turk et al., 2007)

Mix	Slump(mm)	T_{50}(s)	V-funnel		L-Box		
			Flow Time (s)	T $_{5\ min.}$	H_2/H_1	T_{20}	T_{40}
PC	-	-	-	-	-	-	-
SCC	685	2.8	8.02	9.5	0.83	0.8	1.9

Natural gravel with maximum particle size of 5-10 mm and 10-20 mm and natural sand (< 5 mm) were used for PC and SCC. To achieve desired rheological behaviour for SCC, e.g. a slump flow value of 650-800 mm, a super plasticizer (Viscocrete 3075) was used in both SCC mixes, whilst the PC concrete did not contain super plasticizer.
Mix designs for self compacting concretes were developed by means of trial mixes based on guidance given in EFNARC. For SCC, slump flow, t_{50} , L box and V funnel tests as described in EFNARC were carried out. The results obtained from these tests (Table 2.10) showed that SCC mixes had good filling and passing ability as well as segregation resistance.

Pereira-de-oliveira et al. (2005) evaluated slump flow, L box, V funnel test to get the SCC workability. The characteristics and properties of mixtures are presented in the Table 2.11. being used, in accordance with the addition material used, abbreviations. SCCSF for self compacting concrete with silica fume.

Table 2.11: Proportion in mass of the component materials of the tested mixtures (Pereira-de-oliveira et al. 2005)

Ingredients	NC	SCCSF
Cement (Kg)	100	100
Silica Fume (Kg)	-	10
Sand (kg)*2.8	88	111
Sand (kg)*4.5	88	111
Aggregates (6-15) kg	275	229
Water/cement (kg/kg)	0.40	0.55
Super-plasticizer Viscocrete 300	1.50	2.2
Water/powder material	0.40	0.36

*fineness module

Table 2.12. Presents the results of tests carried out to verify the self-compacting of concrete. The results of slump-flow test carried out in SCC concrete characterize the mixtures as being self compacting. However, the mixture SCCSF presents relationships H_1/H_0 below 0.80. This value has been recommended as minimum value for this test that simulates the capacity of concrete transit inside the formwork and it depends on the steel bars density contained.

Table 2.12: Results of Slump-flow, L box and V funnel tests (Pereira-de-oliveira et al., 2005)

		NC	SCCSF
Slump	(mm)	35	-
Slump	Time (seg.)	-	1.34
Flow	Final average dia.(mm)	-	680
L box	T_{40}(seg.)	-	3'93"
	H_1/H_0(cm)	-	0.60
V-funnel	Time (seg.)	-	13'00"

Khaloo and Houseinian (1999) investigated the influence of silica fume on compressive strength and durability of concrete. The percentage of silica fume was between 1% and 15% and the water-cement ratios ranged from 0.3 to 0.6. The coarse and fine aggregates consisted of river gravel and sand with maximum size of 25 mm and 5 mm, respectively. The test results indicated that 5 to 10 percent by mass replacement of silica fume for cement provided the highest strength for short and long terms. Compressive strength of silica fume concrete at 28 days compared to conventional concrete increased by 20 to 40 percent, for all the variables considered. After 300 cycles, all of the concrete specimens passed ASTM C 666 for freezing and thawing durability test.

Ray and Chattopadhyay (1999) carried out studies on the effects of 4, 8, 12, and 16% of silica fume by weight of cement on compressive strength and resistance against chemicals (acids and sulphates) of concretes. For testing of resistance against acids and sulphates 50 mm cubic samples were oven dried at 105ºC and immersed in 2% HNO_3, 2% $H2SO_4$, and 5% Na_2SO_4 solutions for 45 days. The weight and strength losses were noted with reference to a set of undisturbed samples cured in water. Conventional concrete exhibited slight bleeding, but this phenomenon was completely eliminated when silica fume has been added in the mixture. Also, the values of air content decreased with the increase in silica fume content. They dropped from 5.5% for normal concrete to 3.5% for 16% of silica fume replacement. Concretes with a content of 8% silica fume showed the highest compressive strength values after 28 days (45 MPa), followed by concretes having 4, 12, and 16%. Addition of silica fume at all percentages improved the flexural strength, with a significant rise for a 4% content (8.5 MPa). As regarding the resistance against acids and sulphates, test results showed that immersion in H_2SO4 has caused maximum loss in weight and strength, followed by HNO_3 and Na_2SO_4. The maximum strength loss of 24% has occurred for mixtures without any silica fume, whereas the minimum loss of 12% occurred for mixtures containing 4% of silica fume.

The influence of silica fume on workability and compressive strength of concretes were the major research objectives for Duval and Kadri (1998). Concretes that have been investigates had low water-cement ratios (0.25 to 0.40). The type I Portland cement was replaced by 10-30% by mass silica fume and super plasticizer was added. It was found that silica fume increased best the compressive strength (25%) and the workability of concretes when its content was between 4 and 8 percent. Duval and Kadri also found out that if silica fume exceeds 15% of the cementitious material, both compressive and tensile strengths are reduced.

Khayat et al. (1997) evaluated the influence of silica fume blended with cement on some properties of fresh and hardened concrete. The properties studied were bleeding, slump loss, time of setting, compressive strength. A total of 26 commonly used concrete mixtures in the Canadian construction industry were developed. Half of the mixtures were air-entrained and had water cement ratios ranging from 0.3 to 0.6. The remaining half contained non air-entrained mixtures and the water-cement ratios varied between 0.45 and 0.7. Studies undertaken revealed that the addition of small percentages of silica fume, usually fewer than 10%, and proper amount of high range water-reducing admixture (super plasticizer) could decrease the viscosity of the paste, thus reducing the water demand and the risk of bleeding. The small particles of silica fume can displace some of the water present among flocculated cement particles and fill some of the voids between the coarser particles, which otherwise can be occupied by some of the mix water. This causes some gain in workability and densification of the fresh paste. Concrete mixtures made with blended silica fume cement exhibited substantially less bleeding than those made with type I Portland cement. In addition, mixtures made with blended silica fume cement showed 15 to 20 mm greater loss of slump than concretes without silica fume. In general, concrete mixtures made with type I Portland cement and blended silica fume cement exhibited similar initial times of setting that were within one hour apart. When 15% of silica fume was added with a high dosage of super-plasticizer, initial and final times of setting were delayed by approximately 1 and 2 hours, respectively. Regarding the compressive strength.

Khayat et al. (1997) found out that after three days of curing, no effect of cement type was observed on the development of compressive strength for concretes. However, starting with the seventh day, mixtures containing blended silica fume cement exhibited greater strength than those made with type-I Portland cement. After 28 days, in non air-entrained concretes, the use of blended silica fume cement resulted in approximately 20% strength gain compared with mixtures containing only Portland cement. Similar results were obtained in air-entrained concrete.

CHAPTER: 3 EXPERIMENTAL PROGRAMMES

3.1. General

The aim of the experimental program is to compare the properties of Self Compacting concrete made with and without fly ash and silica fume, used as supplementary cementing material. The basic tests carried out on concrete samples are discussed in this chapter, followed by a brief description about mix deign and curing procedure adopted. At the end, the various tests conducted on the specimens are discussed.

3.2. Material 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 make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials clay predominates and in calcareous materials calcium carbonate predominates. Basic composition of cement is shown in Table 3.1.

Table 3.1: Composition limits of Portland cement

Ingredient	**% Content**
CaO(Lime)	60-67
SiO_2 (Silica)	17-25
Al_2O_3(Alumina)	3-8
Fe_2O_3 (Iron Oxide)	0.5-6
MgO(Magnesia)	0.1-4
Alkalies	0.4-1.3
Sulphur	1-3

Grade 43 Ultra Tech cement was used for casting cubes and cylinders for all concrete mixes. The cement was of uniform colour i.e. grey with a light greenish shade and was free from any hard lumps. Summary of the various tests conducted on cement are as under given below in Table 3.2.

Table 3.2: Physical Properties of Cement

S.No.	**Characteristics**	**Values Obtained**	**Standard values**
1.	Normal Consistency	33%	-
2.	Initial Setting time	48 min	Not be less than 30 minutes
3.	Final Setting time	240 min	Not be greater then 600 minutes
4.	Fineness	4.8 %	<10
5.	Specific gravity	3.09	-
Compressive strength:- Cement : Sand (1:3)			
1.	3 days	24.5 N/mm^2	27 N/mm^2
2	7 days	38 N/mm^2	41 N/mm^2
3.	28 days	45 N/mm^2	43 N/mm^2

3.2.2. Fine Aggregates

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 and then was washed to remove the dust. Properties of the fine aggregate used in the experimental work are tabulated in Table 3.3. The aggregates were sieved through a set of sieves to obtain sieve analysis and the same is presented in Table 3.4. The fine aggregated belonged to grading zone III.

Table 3.3: Physical Properties of fine aggregates

Sr. No.	**Characteristics**	**Value**
1.	Specific gravity	2.46
2.	Bulk density	1.4
3.	Fineness modulus	2.56
4.	Water absorption	0.85
5.	Grading Zone (Based on percentage passing 0.60 mm)	Zone III

Table 3.4: Sieve analysis of fine aggregate

Sr. No.	Sieve Size	Mass retained	Percentage Retained	Cumulative Percentage Retained	Percent Passing
1	4.75mm	4.0	0.4	0.4	99.6
2	2.36	75.0	7.50	7.90	92.1
3	1.18	178.0	17.8	25.70	74.3
4	600µm	220.0	22.0	47.70	52.3
5	300µm	274.0	27.4	75.10	24.9
6	150µm	246.5	24.65	99.75	0.25
7	2.50	0.25	0.25	∑=256.55	

Total weight taken = 1000gm

Fineness Modulus of sand = 2.56

3.2.3 Coarse aggregate

The material which is retained on IS sieve no. 4.75 is termed as a coarse aggregate. The crushed stone is generally used as a coarse aggregate. The nature of work decides the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 10 mm was used in our work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested as per IS: 383-1970. The results of various tests conducted on coarse aggregate are given in Table 3.5. and Table 3.6. shows the sieve analysis results.

Table 3.5: Physical Properties of Coarse Aggregates (10 mm)

Sr. No	Characteristics	Value
1	Type	Crushed
2	Specific Gravity	2.66
3	Total Water Absorption	0.56
4	Fineness Modulus	6.83

Table 3.6: Sieve Analysis of Coarse Aggregates (10mm)

Sr. No.	**Sieve Size**	**Mass Retained (gm)**	**Percentage Retained**	**Cumulative Percentage Retained**	**Percent Passing**
1	20 mm	0	0	0	100
2	10 mm	2516	83.89	83.87	16.13
3	4.75	474	15.8	99.67	0.33
4	PAN	10	0.33	∑= 183.54	

Total weight taken = 3Kg

FM of 10 mm Coarse aggregate = $\frac{183.54+500}{100}$ =6.83

3.2.4 Water

Generally, water that is suitable for drinking is satisfactory for use in concrete. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in concrete unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting.

3.2.5 Fly Ash

Class F Fly ash obtained from “Bathinda Thermal Power Station, Bathinda”, Punjab was used.

3.2.6 Silica Fume

Densified silica fume obtained from Mehtab Pvt. Limited.

3.2.7 Admixture

Conplast SP430 complies with IS:9103:1979 and BS:5075 Part 3 and ASTM-C-494 Type ‘F’ as a high range water reducing admixture.

Conplast SP430 is based on Sulphonated Napthalene Polymers 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 degree C.

3.2 8 Mixture Proportioning

Table.3.7: Various mix proportions

Mixture ID	Cement kg/m^3	FA kg/m^3	SF Kg/m^3	FA (%)	SF (%)	Sand kg/m^3	C.A kg/m^3	Water (kg.m^3)	w/p	SP (kg/m^3)	SP (%)
CM	550	0	0	0	0	910	590	252	.45	9.0	1.64
SCC(1)	465	85	-	15	-	910	590	228	.41	10.73	1.95
SCC(2)	415	135	-	25	-	910	590	233.3	.42	9.91	1.80
SCC(3)	355	195	-	35	-	910	590	242	.44	9.91	1.80
SCC(A)	528	-	22	-	4	910	590	228	.48	9.91	1.80
SCC(B)	506	-	44	-	8	910	590	240	.48	9.91	1.80
SCC(C)	484	-	66	-	12	910	590	246	.50	9.91	1.80

3.3 Casting and Curing

For casting, the entire test specimen were cleaned and oiled properly. These were securely 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 procedure was adopted in the batching, mixing and casting operations. The coarse aggregates and fine aggregates were weighed first with an accuracy of 0.5 grams. 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 thoroughly. Then water was added carefully so that no water was lost during mixing.

To this mixture, the cement was added. These were mixed to uniform colour. Then water was added carefully so that no water was lost during mixing. For each mix 15 samples were prepared, which consists of 6 cubes (150x150x150) for 7 and 28 days compressive strength and 6 (300x150) cylinders for split tensile strength at 7 and 28 days and 3 cylinders (200x100) for RCPT.

3.4 Tests Conducted

3.4.1. Fresh Concrete Tests.

EFNARC (2002) SCC differs from conventional concrete in that its fresh properties are vital in determining whether or not it can be placed satisfactorily. The various aspects of workability which control its Filling ability, its Passing ability and its Segregation resistance all need to be carefully controlled to ensure that its ability to be placed remains acceptable.

A concrete mix can only be classified as Self-compacting Concrete if the requirements 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 during and after the process of transport and placing.

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

3.4.1.1. U- Box Test Method

Introduction

The test was developed by the Technology Research Centre of the Taisei Corporation in Japan. Sometimes the apparatus is called a “box-shaped” test. The test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments, shown by R1 and R2 in Figure 3.1.

An opening with a sliding gate is fitted between the two sections. Reinforcing bars with nominal diameters of 13 mm are installed at the gate with centre-to-centre spacing of 50 mm. This creates a clear spacing of 35 mm between the bars. The left hand section is filled with about 20 litre of concrete then the gate lifted and concrete flows *upwards* into the other section. The height of the concrete in both sections is measured.

Assessment of test

This is a simple test to conduct, but the equipment may be difficult to construct. It provides a good direct assessment of filling ability – this is literally what the concrete has to do – modified by an unmeasured requirement for passing ability. The 35mm gap between the sections of reinforcement may be considered too close. The question remains open of what filling height less than 30 cm. is still acceptable.

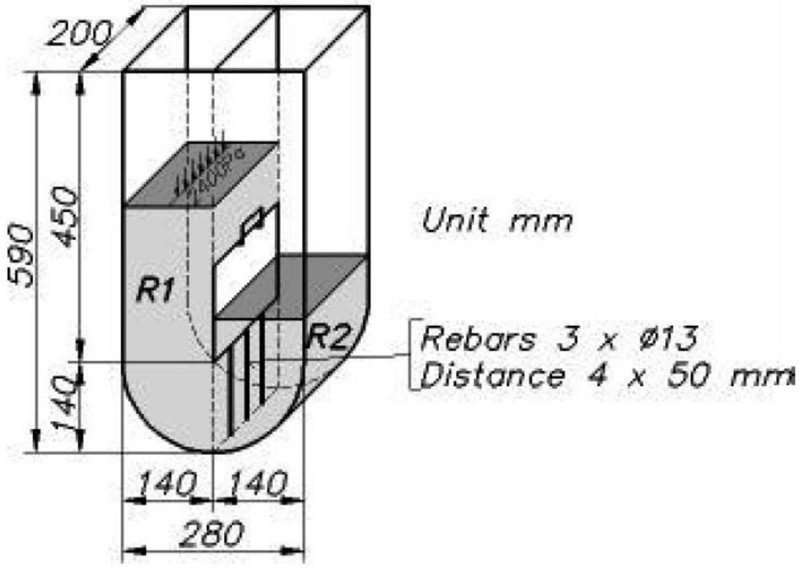

Figure 3.1: U box. (EFNARC, 2002).

Equipment

- U box of a stiff non absorbing material see figure 3.1.
- trowel
- scoop
- stopwatch

Procedure

About 20 litre of concrete is needed to perform the test, sampled normally.

Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.

Moisten the inside surfaces of the apparatus, remove any surplus water.

Fill the one compartment of the apparatus with the concrete sample.

Leave it to stand for 1 minute.

Lift 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 calculate the mean (H1). Measure also the height in the other compartment (H2)

Calculate H1 - H2, the filling height.

The whole test has to be performed within 5 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so H1 - H2 = 0. Therefore the nearer this test value, the 'filling height', is to zero, the better the flow and passing ability of the concrete.

3.4.1.2. L- Box Test Method

Introduction

This test is based on a Japanese design for underwater concrete. The test assesses the flow of the concrete, and also the extent to which it is subject to blocking by reinforcement. The apparatus is shown in Figure 3.2.

The apparatus consists of a rectangular-section box in the shape of an 'L', with a vertical and horizontal section, separated by a moveable gate, in front of which vertical lengths of reinforcement bar are 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 stopped, the height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H2/H1in the diagram). It indicates the slope of the concrete when at rest. This is an indication 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 200mm and 400mm from the gate and the times taken to reach these points measured. These are known as the T20 and T40 times and are an indication for the filling ability.

The sections of bar can be of different diameters and spaced at different intervals: in accordance with normal reinforcement considerations, 3x the maximum aggregate size might be appropriate. The bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete.

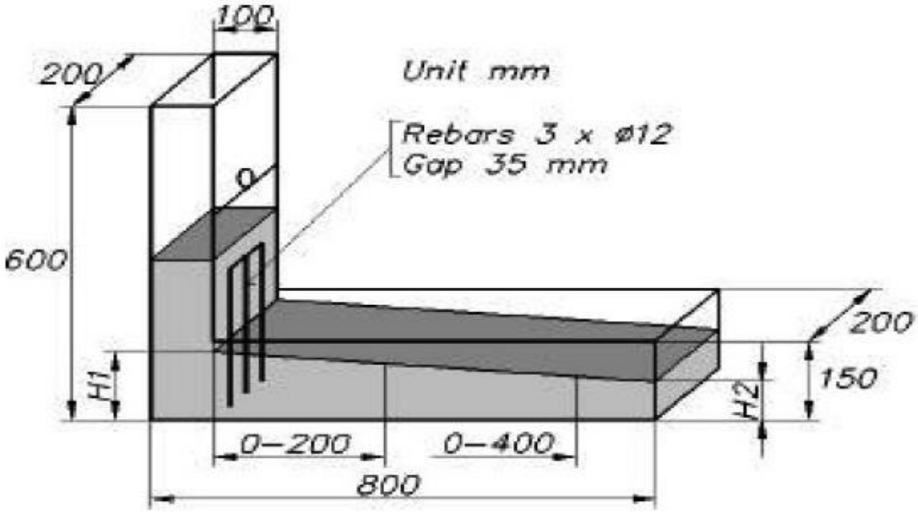

Figure 3.2: L box. (EFNARC, 2002).

Assessment of test

This is a widely used test, suitable for laboratory, and perhaps site use. It assesses filling and passing ability of SCC, and serious lack of stability (segregation) can be detected visually. Segregation may also be detected by subsequently sawing and inspecting sections of the concrete in the horizontal section. Unfortunately there is no agreement on materials, dimensions, or reinforcing bar arrangement, so it is difficult to compare test results. There is no evidence of what effect the wall of the apparatus and the consequent 'wall effect' might have on the concrete flow, but this arrangement does, to some extent, replicate what happens to concrete on site when it is confined within formwork.

Two operators are required if times are measured, and a degree of operator error is inevitable.

Equipment

- L box of a stiff non absorbing material see Figure 3.2.
- Trowel
- scoop
- stopwatch

Procedure

About 14 litre of concrete is needed to perform the test, sampled normally.

Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it.

Moisten the inside surfaces of the apparatus, remove any surplus water.

Fill the vertical section of the apparatus with the concrete sample.

Leave it to stand for 1 minute.

Lift 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 reach the 200 and 400 mm marks.

When the concrete stops flowing, the distances "H1" and "H2" are measured.

Calculate H2/H1, the blocking ratio.

The whole test has to be performed within 5 minutes.

Interpretation of result

If the concrete flows as freely as water, at rest it will be horizontal, so H2/H1 = 1. Therefore the nearer this test value, the 'blocking ratio', is to unity, the better the flow of the concrete. The EU research team suggested a minimum acceptable value of 0.8. T20 and T40 times can give some indication of ease of flow, but no suitable values have been generally agreed. Obvious blocking of coarse aggregate behind the reinforcing bars can be detected visually.

3.4.1.3. V-Funnel Test Method

Introduction

The test was developed in Japan and used by Ozawa. The equipment consists of a V-shaped funnel, shown in Figure 3.3. An alternative type of V-funnel, the O funnel, with a circular section is also used in Japan. The described V-funnel test is used to determine the filling ability (flow ability) of the concrete with a maximum aggregate size of 20mm. The funnel is filled with about 12 litres of concrete and the time taken for it to flow through the apparatus measured. After this the funnel can be refilled concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

Assessment of test

Though the test is designed to measure flow ability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result – if, for example there is too much coarse aggregate. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. While the apparatus is simple, the effect of the angle of the funnel and the wall effect on the flow of concrete are not clear.

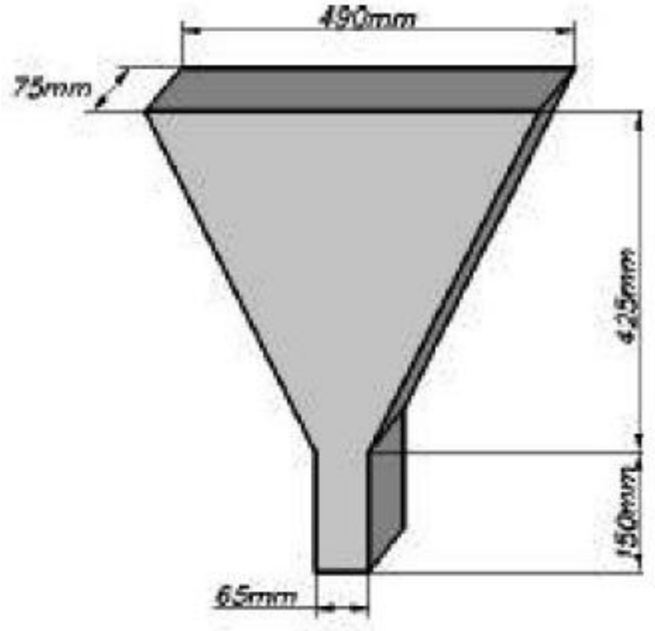

Figure 3.3: V- Funnel equipment. (EFNARC, 2002).

Equipments

- V-funnel
- bucket (±12 litre)
- trowel
- scoop

- stopwatch

Procedure flow time

About 12 litre of concrete is needed to perform the test, sampled normally.

Set the V-funnel on firm ground.

Moisten the inside surfaces of the funnel.

Keep the trap door open to allow any surplus water to drain.

Close the trap door and place a bucket underneath.

Fill the apparatus completely with concrete without compacting or tamping, simply strike off the concrete level with the top with the trowel.

Open 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 discharge 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 minutes.

Interpretation of result

This test measures the ease of flow of the concrete; shorter flow times indicate greater flow ability. For SCC a flow time of 10 seconds is considered appropriate. The inverted cone shape restricts flow, and prolonged flow times may give some indication of the susceptibility of the mix to blocking. After 5 minutes of settling, segregation of concrete will show a less continuous flow with an increase in flow time.

3.4.1.4. Slump Flow Test.

Introduction

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete.

Assessment of test

This is a simple, rapid test procedure, though two people are needed if the T_{50} time is to be measured. It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is the most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

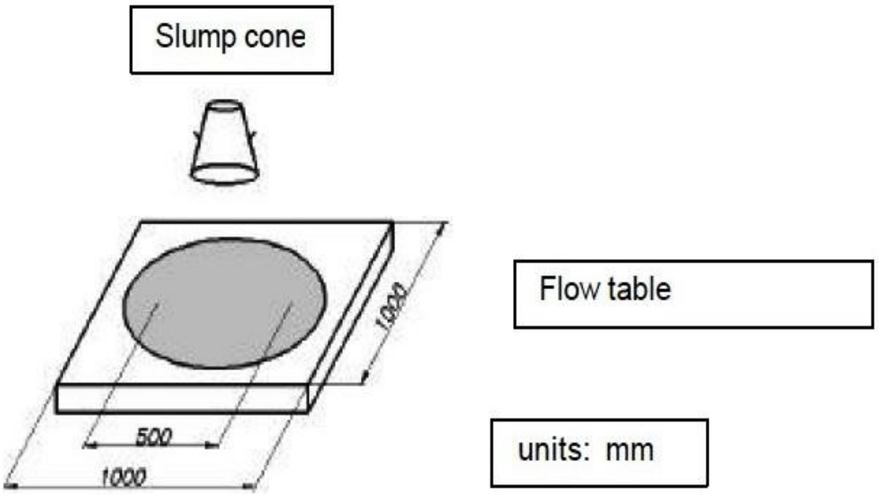

Figure 3.4: Slump flow test equipment. (EFNARC, 2002).

Equipment

The apparatus is shown in Figure 3.4

- Mould in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm, conforming to EN 12350-2
- Base plate of a stiff non absorbing material, at least 700mm square, marked with a circle marking the central location for the slump cone, and a further concentric circle of 500mm diameter
- trowel
- scoop
- ruler
- stopwatch (optional)

Procedure

About 6 litre of concrete is needed to perform the test, sampled normally.

Moisten the base plate and inside of slump cone, Place base plate on level stable ground and the slump cone centrally on the base plate and hold down firmly.

Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel.

Remove any surplus concrete from around the base of the cone.

Raise the cone vertically and allow the concrete to flow out freely.

Simultaneously, start the stopwatch and record the time taken for the concrete to reach the 500mm spread circle. (This is the T50 time).

Measure the final diameter of the concrete in two perpendicular directions.

Calculate the average of the two measured diameters. (This is the slump flow in mm).

Note any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

Interpretation of result

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A value of at least 650mm is required for SCC. There is no generally accepted advice on what are reasonable tolerances about a specified value, though ± 50mm, as with the related flow table test, might be appropriate. The T50 time is a secondary indication of flow. A lower time indicates greater flow-ability. The Brite EuRam research suggested that a time of 3-7 seconds is acceptable for civil engineering applications, and 2-5 seconds for housing applications. In case of severe segregation most coarse aggregate will remain in the centre of the pool of concrete and mortar and cement paste at the concrete periphery. In case of minor segregation a border of mortar without coarse aggregate can occur at the edge of the pool of concrete. If none of these phenomena appear it is no assurance that segregation will not occur since this is a time related aspect that can occur after a longer period.

3.4.2 Hardened Concrete test

3.4.2.1 Compressive Strength Test (IS: 516 – 1959)

Aim

Determine the compressive strength of concrete specimens.

Apparatus

Testing Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified. The permissible error shall be not greater than ± 2 percent of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the platens (preferably the one that normally will bear on the upper surface of the specimen) shall be fitted with a ball seating in the form of a portion of a sphere, the centre of which coincides with the central point of the face of the platen. The other compression platen shall be plain rigid bearing block. The bearing faces of both platens shall be at least as large as, and preferably larger than the nominal size of the specimen to which the load is applied. The bearing surface of the platens, when new, shall not depart from a plane by more than 0.01 mm at any point, and they shall be maintained with a permissible variation limit of 0.02 mm. The movable portion of the spherically seated compression platen 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.

Age at Test

Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. Ages of 13 weeks and one year are recommended if tests at greater ages are required. Where it may be necessary to obtain the early strengths, tests may be made at the ages of 24 hours ± ½ hour and 72 hours ± 2 hours. The ages shall be calculated from the time of the addition of water to the dry ingredients.

Number of Specimens

At least three specimens, preferably from different batches, shall be made for testing at each selected age.

3.4.2.2 Splitting Tensile Strength Test (ASTM C496)

Apparatus

Compression Testing Machine

Bearing Strips - 2 each, 1/8 in. thick plywood strips, 1 in. wide (the length shall be slightly longer that of the specimens). The bearing strips are placed between the specimen and the upper and lower bearing blocks of the testing machine (or between the specimen and supplementary bearing bars if used). Supplementary Bearing Bars - Steel bar 2 in. wide, 3 in. thick, and 12 in. long.

Materials

6” x 12” Moist cured concrete cylinders

Procedure

1) Draw diametric lines on each end of the specimen so that they are in the same axial plane.
2) Centre one of the plywood strips along 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 centred over the plywood strip.
4) Place the second plywood strip and the bearing bar so that they are lengthwise on the cylinder, centred on the previously marked lines on the ends.
5) Apply the load continuously at a constant rate of 100 to 200 psi/minute of splitting tensile stress until failure occurs (the load rate is 11000 to 22000 lb/minute for 6”diameter by 12” long specimens).
6) Record the maximum load at failure.
7) Calculate the splitting tensile strength as follows:

$$f_{st}^{'} = \frac{2P}{\pi \; ld}$$

Where P is the maximum load at failure in pounds, and l and d are the length and diameter of the cylindrical specimen, respectively, in inches.

Report

1) Report the type of concrete, unit weight, and unconfined compressive strength.
2) Report the splitting tensile strength to the nearest 5 psi.

3.5 Rapid Chloride Permeability Test

The rapid chloride permeability test 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 bit (alternatively, tests are performed using 4 in. (100 mm) diameter cast cylinders, and the test values are normalized using the ratio of the standard to the actual cross-sectional areas). 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 hours. As shown in Fig. 3.5. and Fig. 3.6. The specimen is then placed in the testing apparatus where one end of the specimen is exposed to a solution containing sodium chloride (NaCl) and the other end is exposed to a solution containing 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 minutes during the 6-hour 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, however, these effects are small relative to changes in conductivity due to temperature rise. To reduce the effects of heating and resultant changes in conductivity over the 6-hour period of the test, it’s been suggested that earlier values be adjusted to obtain an equivalent 6-hour coulomb value. For example, data taken at 30 minutes would be multiplied by 12 to obtain an equivalent 6-hour value. Because the test results are highly variable (as with most, if not all, penetration resistance tests), two or three specimens are usually tested for each concrete sample. 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. The original researchers found good correlation between the coulomb values and the results of ponding tests performed on specimens from the same mixture for a wide variety of concretes.

Fig.3.5: Rapid chloride permeability test set up (ASTM C 1202).

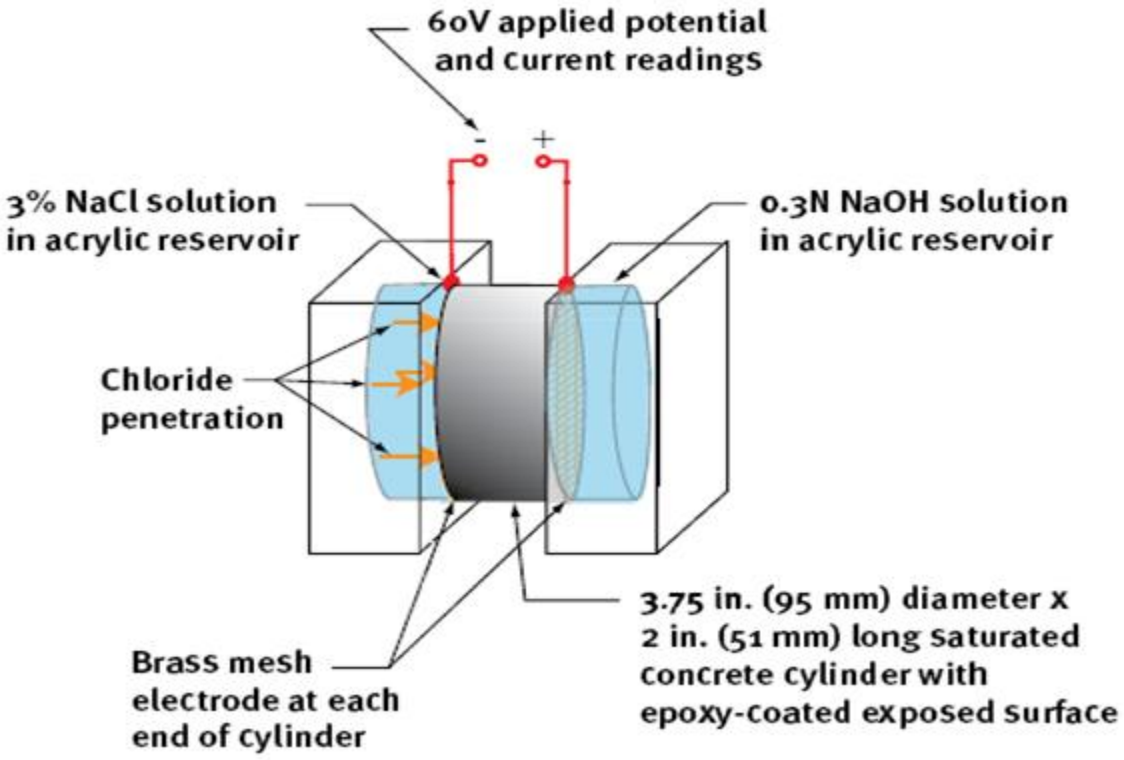

Fig.3.6: Schematic of rapid chloride permeability test setup

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 recommends the use of the qualitative terms shown in the right-hand column of Table 1, rather than the numerical results of the test.

Table.3.8: Chloride ion penetrability based on charge passed (ASTM 1202-97).

Charge passed coloumbs	Chloride ion penetrability
>4000	High
2000-4000	Moderate
1000-2000	Low
100-1000	Very Low
<100	Negligible

CHAPTER: 4 RESULTS AND DISCUSSIONS

4.1. General

In this chapter the parameters studied on the control and concrete made with replacement of fly ash and silica fume with cement in self-compacting concrete are discussed. The parameters such as Compressive strength, Splitting Tensile Strength, Rapid Chloride Permeability are discussed and comparisons between the various mixes are represented.

4.2. Fly Ash

4.2.1. Fresh Concrete Properties

In order to study the effect on fresh concrete properties when fly ash is added into the concrete as cement replacement, the SCC containing different proportion of fly ash were tested for Slump flow, V-funnel, U-Box, L-box.

The results of fresh properties of all Self-compacting fly ash concretes are included in Table 4.1. The table shows the properties such as slump flow, V-funnel flow times, L-box, U- box. In terms of slump flow, all SCCs exhibited satisfactory slump flows in the range of 550–800 mm, which is an indication of a good deformability.

Table: 4.1: Fresh concrete properties (Fly Ash)

Mixture ID	Slump (mm)	V-funnel (seconds)	L-Box (H2/H1)	U-box(H1-H2)
SCC1(15% FA)	687	9	0.9	30
SCC1(15% FA)	590	13	-	-
SCC2(25% FA)	704	11	-	35
SCC2(25% FA)	740	12	0.9	35
SCC2(25% FA)	720	9	1.0	-
SCC3(35% FA)	630	-	-	40
SCC3(35% FA)	680	13	-	-
SCC3(35% FA)	640	11	0.8	30

As per EFNARC, time ranging from 6 to 12 seconds is considered adequate for a SCC. The V-funnel flow times were in the range of 4–10 seconds. Test results of this investigation indicated that all SCC mixes meet the requirements of allowable flow time. Maximum size of coarse aggregate was kept as 16 mm in order to avoid blocking effect in the L-box. The gap between rebars in L-box test was 35 mm. The L-box ratio H2/H1 for the mixes was above 0.8 which is as per EFNARC standards. U-box difference in height of concrete in two compartments was in the range of 5–40 mm. All the fresh properties of concrete values were in good agreement to that of the values given by European guidelines.

Fig. 4.1: Slump flow test.

Fig. 4.2: L-Box test.

4.2.2. Compressive Strength

In order to study the effect on compressive strength when fly ash is added into self-compacting concrete as cement replacement, the cube containing different proportion of fly ash were prepared and kept for curing for 7, 28 and 56 days. The test was conducted on ASTM of capacity 3000 KN. From the results Table 4.2. It is obtained that 56 days strength of all the mixes is invariably higher than corresponding 7 days and 28 days strength. This is due to continuous hydration of cement with concrete.

Table 4.2: Compressive strength of SCC mixes with Fly Ash

MIX	**Compressive Strength (N/mm^2)**			**Average Compressive Strength(N/mm^2)**		
	7 days	28days	56 days	7 days	28 days	56 days
SCC1 (15% FA)	19	27.5	36.5	18.9	27.7	38.1
	18.4	26.9	38.7			
	19.3	28.7	39.2			
SCC2 (25% FA)	16.1	24.7	33.7	17.1	24.3	32.5
	16.7	23.6	31.4			
	18.5	24.6	32.4			
SCC3 (35% FA)	15.6	22.7	29.7	14.6	22.3	29.1
	14.6	22.9	30.0			
	13.5	21.2	27.8			
CM	20.2	28.4	36.1	20.6	28.9	33.0
	23.5	29.5	31.0			
	18	28.7	32.1			

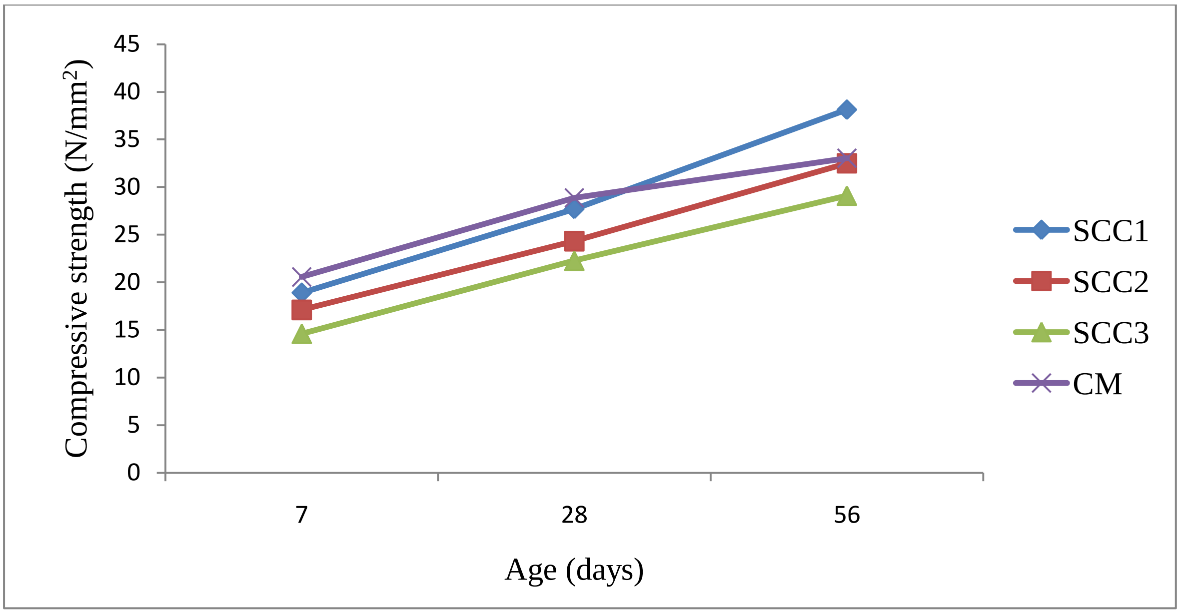

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Fig.4.3: Compressive strength of SCC mixes at various ages.

Effect of percentage of Fly ash on compressive strength of self-compacting concrete

The compressive strength tests results of SCC mixes are given in table 4.2. and shown in fig. 4.3. With the increase in fly ash content from 15–35%, SCC mixes developed compressive strengths between 18.9 and 13.9 MPa at 7 days; between 27.7 and 20.8 at 28 days; between 38.1 and 26.6 at 56 days. The compressive increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio. An increase of about 24% strength at 28 days and 30% at 56 days was observed with the decrease of fly ash content from 35% (SCC3) to 15% (SCC1). The strength values at 7 days of SCC5 (35% fly ash) are comparable with the results reported by Siddique (2010).

For the same mix, the strength values corresponded to those reported by Xie et al. (2000) at 28 days age of curing. SCC4 (30% fly ash) attained strength of 23.98 MPa, 30.66 MPa, at 7 and 28, days, respectively. Similarly, SCC3 (25% fly ash) attained strength corresponding to 25.52 MPa, 31.47 MPa, at 7 and 28 days, respectively.

4.2.3 Splitting Tensile Strength

Split tensile strength studies were carried out at the age of 28 days and 56 days only. For instance it can be seen from the Fig.4.4. the tensile strength increases in (SCC1) as replacement of fly ash with cement in comparison with control mix. With further increase in percentage of fly ash in self-compacting concrete the tensile strength decreases .Almost same with control mix at 25% fly ash replacement at 56 days results. Tensile strength decrease with the increase of fly ash percentage as given in the Table 4.3.

Table 4.3: Splitting Tensile strength of SCC mixes with Fly Ash.

MIX	**Tensile strength (N/mm^2)**		**Average tensile strength (N/mm^2)**	
	28 days	56 days	28 days	56 days
SCC1 (15% FA)	1.9	2.4	1.9	2.3
	2.0	2.3		
	1.9	2.2		
SCC2 (25% FA)	1.8	1.9	1.7	1.8
	1.6	1.9		
	1.5	1.8		
SCC3 (35% FA)	1.6	1.8	1.6	1.7
	1.5	1.6		
	1.4	1.5		
CM	1.8	1.8	1.6	1.8
	1.7	1.8		
	1.3	1.7		

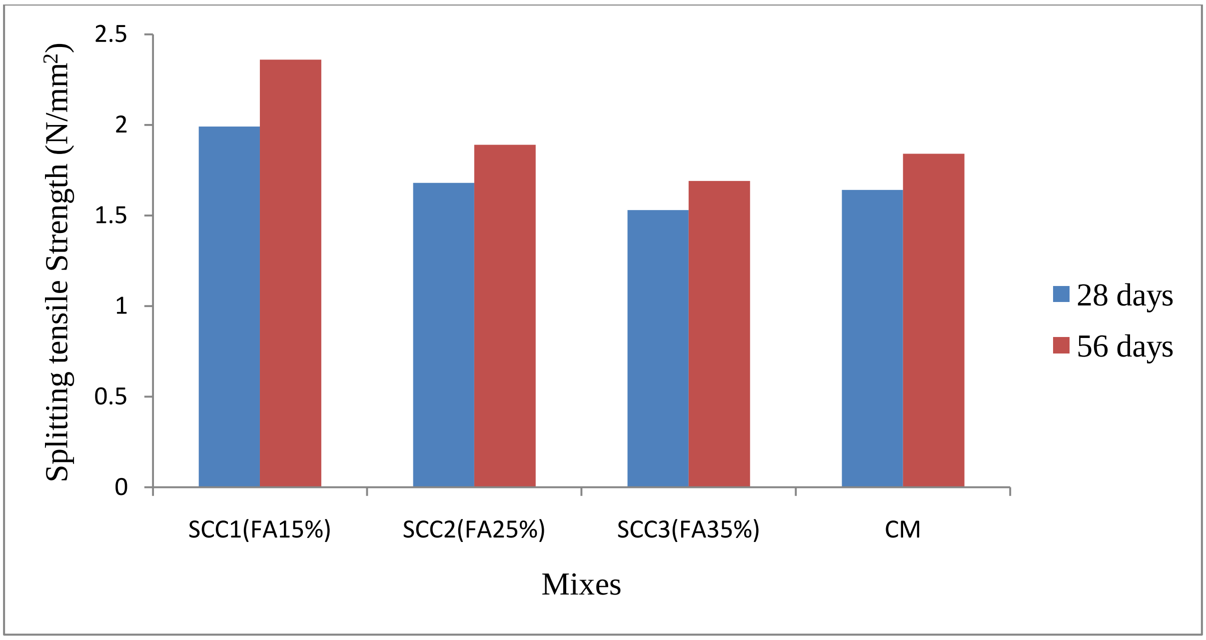

Fig.4.4. Tensile strength of SCC mixes at various ages.

Splitting tensile strength test results of SCC mixes are given in Table 4.3, and shown in Fig. 4.4. SCC mixes achieved splitting tensile strength from 1.5 to 1.9 N/mm^2, 1.7 to 2.3 N/mm^2 at 28 and 56 days, with the increase in fly ash content from 15% to 35%. Splitting tensile strength increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio. With the increase in cement content, the strength of SCC1 (15% fly ash) gradually increased to 1.9 N/mm^2 at 28 days. An increase of about 30% of strength at 28 days and 40% at 56 days was observed with the decrease of the fly ash contents from 35% (SCC3) to 15% (SCC1). As the percentage of fly ash in mixes decreased, the tensile strength increased at all ages. The value of split tensile strength was reported as 3.1N/mm^2 at 28 days by (Turk et al., 2010).

4.2.4 Rapid Chloride Permeability

The measurement concerns the chloride ions that come into concrete and also those flowing through the samples. It was reported that the use of fly ash decreased the rapid chloride penetration Coulomb value of concrete and the presence of fly ash could improve the permeability of concrete due to its capability of transforming large pores of concrete into small pores and reducing micro cracking in the transition zone. The reduction of chloride migration due to presence of fly ash can be explained partially by the fact that spherical particles of fly ash could improve the particle density in the matrix and the interface zone between aggregates and paste.

Table: 4.4: Charge passed and rating for SCC mixes.

Mix	**28 days**		**56 days**	
	Charge passed in coulombs (C)	Chloride ion penetrability	Charge passed in coulombs (C)	Chloride ion penetrability
CM	1782	Low	1663	Low
SCC1 (15% FA)	1392	Low	1134	Low
SCC2 (25%FA)	1213	Low	981	Very Low
SCC3 (35% FA)	1253	Low	934	Very Low

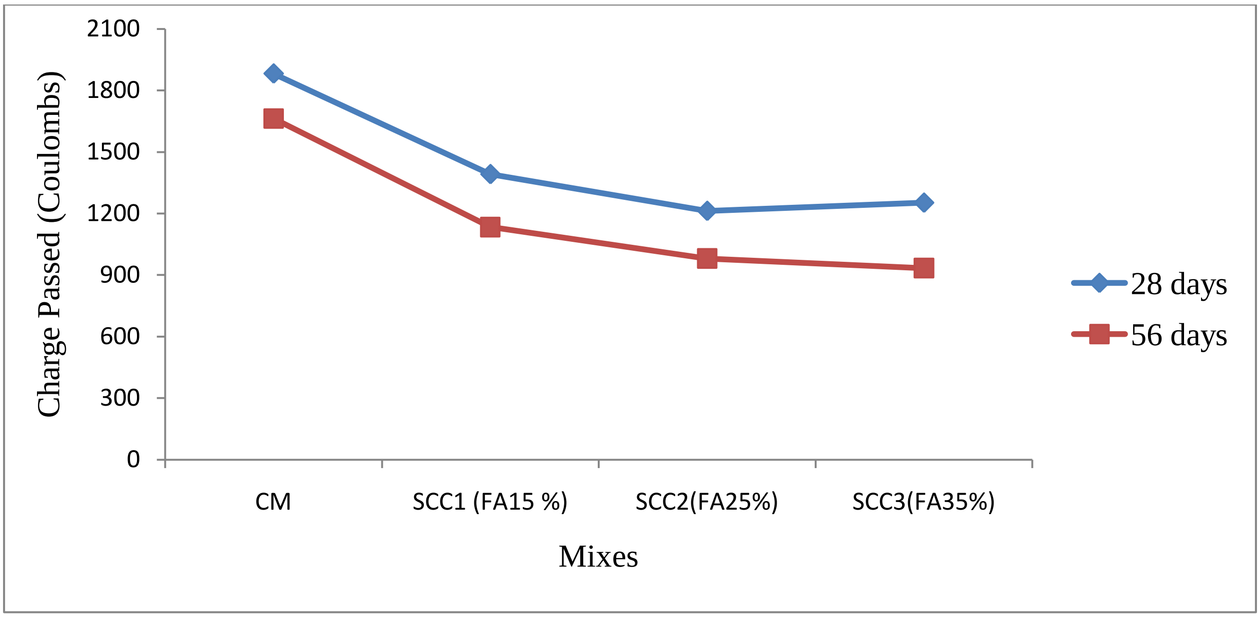

Fig.4.5: Chloride penetration for SCC mixes at various fly ash content.

Rapid chloride permeability test results of SCC mixes are given in Table.4.4. and shown in Fig.4.5. It is evident from these results that all SCC mixes made with fly ash reduced the rapid chloride ion penetrability to the very low range (less than 1400 and 1150 Coulomb) at the age of 28 and 56 days respectively.

The incorporation of fly ash resulted in a reduction in Coulomb charges. The Coulomb charge of SCC(3) (35% fly ash) was 934 Coulomb at 56 days, indicating high chloride penetration resistance. In the thesis, the charge in the mixes varied with the increase in fly ash content. For SCC(2) (25% fly ash) penetration is least. Patel et al. (2004) reported rapid chloride penetration range between 772 and 1379 Coulombs when the fly ash percentages were between 30% and 60%.

Nehdi et al. (2004) have reported that the presence of fly ash reduced the penetrability from approximately 3000 Coulomb to less than 1000 Coulomb. In no case the value of the charges passed was greater than 700 Coulomb implying dense SCC mix structure. The significant reduction in chloride ion penetration may be due to incorporation of fly ash whose spherical particles could improve particle-packing density in the matrix.

4.3. Silica Fume

Because of the extreme fineness and very high amorphous silicon dioxide content, silica fume is a very reactive pozzolanic material. As the Portland cement in concrete begins to react chemically, it releases calcium hydroxide. The silica fume reacts with this calcium hydroxide to form additional binder material called calcium silicate hydrate, which is very similar to the calcium silicate hydrate formed from Portland cement. It is an additional binder that gives silica-fume concrete its improved properties.

Mechanism of silica fume in concrete can be studied basically under three roles:

- **Pore-size Refinement and Matrix Densification:** The presence of silica fume in the Portland cement concrete mixes causes considerable reduction in the volume of large pores at all ages. It basically acts as filler due to its fineness and because of which it fits into spaces between grains in the same way that sand fills the spaces between particles of coarse aggregates and cement grains fill the spaces between fine aggregates grains.
- **Reaction with Free-Lime (From Hydration of Cement)** CH crystals in Portland cement pastes are a source of weakness because cracks can easily propagate through or within these crystals without any significant resistance affecting the strength, durability and other properties of concrete. Silica fume which is siliceous and aluminious material reacts with CH resulting reduction in CH content in addition to forming strength contributing cementitious products which in other words can be termed as ‘‘Pozzolanic Reaction’’.
- **Cement Paste–Aggregate Interfacial Refinement** In concrete the characteristics of the transition zone between the aggregate particles and cement paste plays a significant role in the cement-aggregate bond. Silica fume addition influences the thickness of transition phase in mortars and the degree of the orientation of the CH crystals in it. The thickness compared with mortar containing only ordinary Portland cement decreases and reduction in degree of orientation of CH crystals in transition phase with the addition of silica fume. Hence mechanical properties and durability is improved because of the enhancement in interfacial or bond strength. Mechanism behind is not only connected to chemical formation of C–S–H (i.e. pozzolanic reaction) at interface, but also to the microstructure modification (i.e. CH) orientation, porosity and transition zone thickness) as well.

4.3.1 Fresh Concrete Properties

In order to study the effect on fresh concrete properties when silica fume is added into the concrete as cement replacement, the SCC containing different proportion of silica fume were tested for Slump flow, V-funnel, U-Box, L-box.

The results of fresh properties of all Self-compacting silica fume concretes are included in Table 4.5. The table shows the properties such as slump flow, V-funnel flow times, L-box, U- box. In terms of slump flow, all SCCs exhibited satisfactory slump flows in the range of 550–800 mm, which is an indication of a good deformability.

Table 4.5: Fresh Concrete Properties (Silica fume)

Mixture ID	Slump (mm)	V-funnel (seconds)	L-Box (H2/H1)	U-box(H1-H2)
SCC A (4% SF)	600	11	0.9	34
SCC B (8% SF)	640	13	0.9	40
SCC C (12% SF)	670	9	0.9	35

As per EFNARC, time ranging from 6 to 12 seconds is considered adequate for a SCC. The V-funnel flow times were in the range of 4–10 seconds. Test results of this investigation indicated that all SCC mixes meet the requirements of allowable flow time. Maximum size of coarse aggregate was kept as 16 mm in order to avoid blocking effect in the L-box. The gap between re-bars in L-box test was 35 mm. The L-box ratio H2/H1 for the mixes was above 0.8 which is as per EFNARC standards. U-box difference in height of concrete in two compartments was in the range of 5–40 mm. All the Fresh properties of concrete values were in good agreement to that of the values given by European guidelines.

4.3.2 Compressive Strength

In order to study the effect on compressive strength, when Silica fume is added into self-compacting concrete as cement replacement, the cube containing different proportion of silica fume were prepared and kept for curing for 7, 28 days.

Table 4.6: Compressive strength of SCC mixes with Silica fume

MIX	Compressive Strength (N/mm^2)		Average Compressive Strength (N/mm^2)	
	7 days	28 days	7 days	28 days
SCC A (4% SF)	26.8	37.1	26.9	39.7
	25.7	42.1		
	28.2	39.8		
SCC B (8% SF)	27.7	40.1	29.6	41.4
	30.1	42.3		
	31.0	41.7		
SCC C (12% SF)	25.1	33.4	25.3	37.2
	24.1	37.8		
	26.8	40.3		
CM	20.2	28.4	20.5	28.9
	23.5	29.5		
	18	28.7		

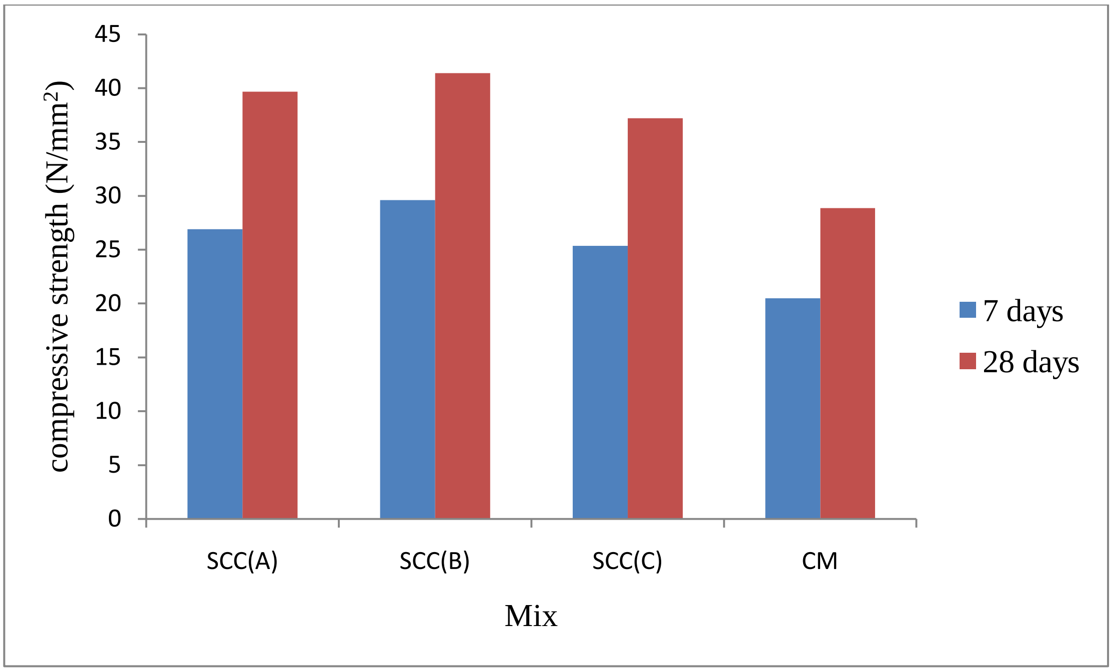

Fig.4.6: Compressive strength of SCC mixes at various ages with Silica fume.

The influence of silica fume on compressive strength of self-compacting concrete is given in Table 4.6. and fig.4.6. The percentage of silica fume was 4%, 8% and 12% and the water-cement ratios ranged from 0.4 to 0.5. The test results indicated that, 4 to 8 percent by mass replacement of silica fume for cement gives the highest strength for short and long terms and when silica fume is replaced by 12% the strength decreases. Compressive strength of silica fume concrete at 28 days compared to control mix was increased by 37 to 50 percent with silica added 4 to 8% respectively.

Khaloo and Houseinian (1999) has reported that the compressive strength of silica fume concrete at 28 days compared to control mix increases by 20 to 40 percent, for all the variables considered.

4.3.3 Splitting Tensile Strength

Split tensile strength studies were carried out at the age of 7 days and 28 days only. As shown in Fig.4.7. and Table.4.7.

Table.4.7: Splitting tensile strength of SCC mixes with Silica fume

MIX	**Splitting Tensile Strength (N/mm^2)**		**Average Splitting Tensile Strength (N/mm^2)**	
	7 days	28 days	7 days	28 days
SCC A (4% SF)	2.1	2.8	2.0	2.9
	2.0	3.1		
	1.9	3.0		
SCC B (8% SF)	2.4	3.1	2.3	3.1
	2.1	3.2		
	2.3	3.0		
SCC C (12% SF)	1.8	3.0	1.9	2.9
	1.9	2.8		
	2.1	2.9		
CM	1.8	1.8	1.6	1.8
	1.7	1.8		
	1.32	1.7		

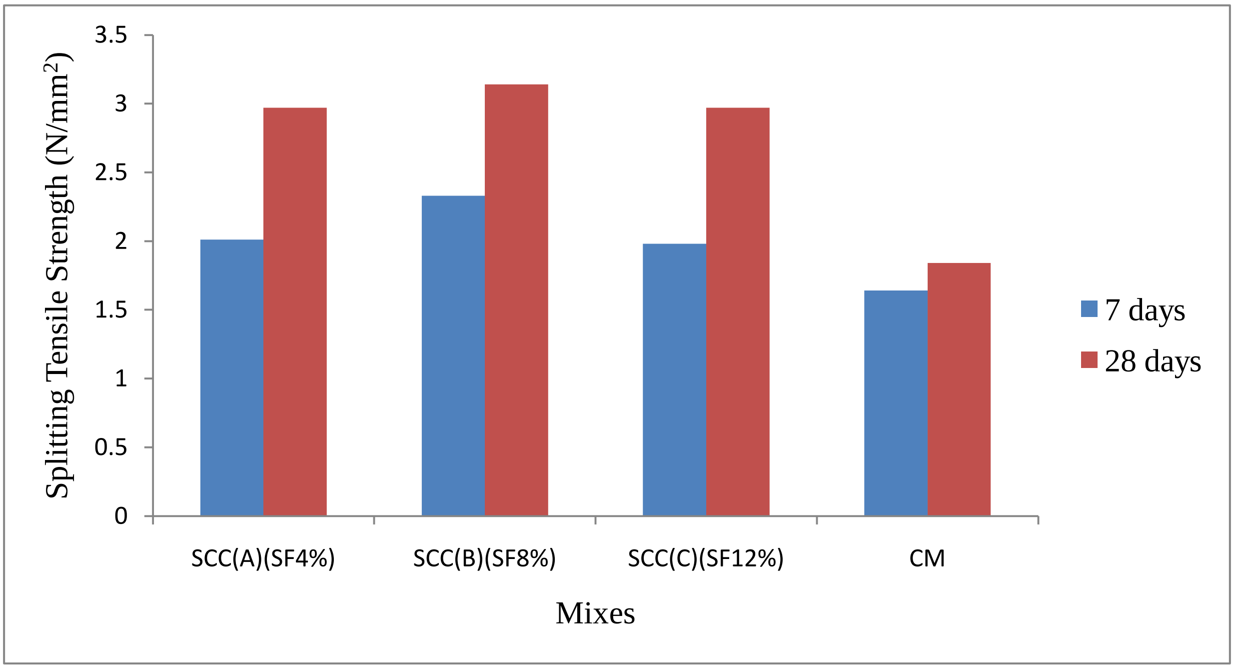

Fig.4.7: Splitting tensile strength of SCC mixes at various ages with Silica fume.

The influences of silica fume on Splitting Tensile Strength of self-compacting concrete e. The percentage of silica fume was 4%, 8% and 12% and the water-cement ratios ranged from 0.4 to 0.5. The test results indicated that 4 to 8 percent by mass replacement of silica fume for cement provided the highest strength for short and long terms. When we increase the replacement of silica fume at 12% it goes on decreasing. Splitting tensile strength of silica fume concrete at 28 days compared to conventional concrete/Control mix increased by 50 to 70 percent with silica added 4 to 8% respectively. Compressive strength of silica fume concrete at 28 days compared to conventional concrete increased by 90 to 120 percent, for all the variables considered reported by (Turk et al., 2010).

4.3.4 Rapid Chloride Permeability

The measurement concerns the chloride ions that come into concrete and also those flowing through the samples. It was reported that the use of Silica fume decreased the rapid chloride penetration Coulomb value of concrete and the presence of silica fume could improve the permeability of concrete due to its capability of transforming large pores of concrete into small pores and reducing micro cracking in the transition zone (Siddique, 2010). The reduction of chloride migration due to presence of silica fume can be explained partially by the fact that spherical particles of fly ash could improve the particle density in the matrix and the interface zone between aggregates and paste.

Table.4.8: Charge passed and rating for SCC mixes.

Mix	**28 days**	
	Charge passed in Coulombs (C)	Chloride ion penetrability
CM	1782	Low
SCC1 (4% SF)	982	Very Low
SCC2 (8%SF)	923	Very Low
SCC3 (12% SF)	846	Very Low

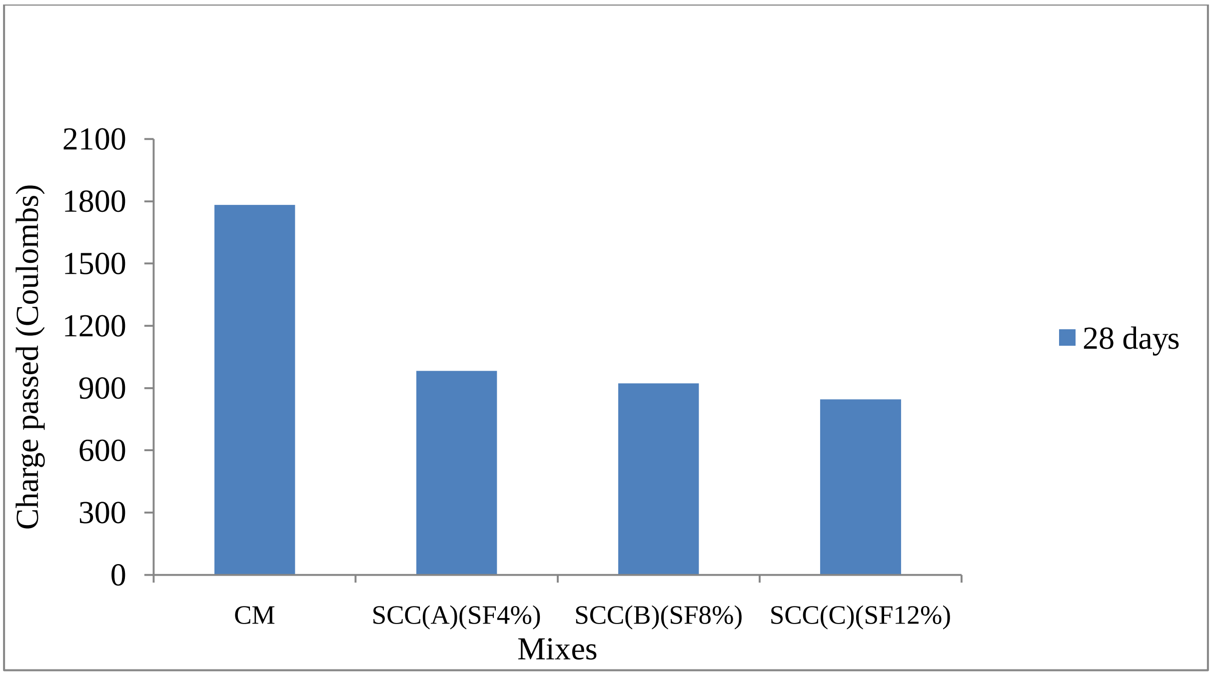

Fig.4.8: Chloride penetration for SCC mixes at various Silica Fume content.

Rapid chloride permeability test results of SCC mixes are given in Table.4.8 and shown in Fig.4.8. It is evident from these results that all SCC mixes made with Silica fume reduced the rapid chloride ion penetrability to the very low range (less than 1000 Coulomb) at the age of 28 days.

The incorporation of Silica fume resulted in a reduction in Coulomb charges. The Coulomb charge of SCC(C) (12% Silica fume) was 846 Coulomb at 28 days, indicating high chloride penetration resistance. In the experiment, the charge in the mixes varied with the increase in silica fume content. For SCC(C) (12% Silica Fume) penetration is least. The significant reduction in chloride ion penetration may be due to incorporation of Silica Fume whose spherical particles could improve particle-packing density in the matrix. Due to increase the content of silica fume (up to 12% in this report) the rapid chloride penetration Coulomb value of Self-compacting concrete is decreased.

CHAPTER: 5 CONCLUSIONS

Following observations have been made from the study by using Fly ash and Silica fume:

- The present results has shown that it is possible to design an SCC mixes incorporating fly ash and silica fume content up to 35% and 12% respectively. The SCC mixes have a slump flow in the range of 600–700 mm, V-funnel time in the range of 4–10 s, 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.

- The SCC mixes developed compressive strengths ranging from 15 to 19 N/mm^2, from 23 to 28 N/mm^2, from 30 to 39 N/mm^2 at 7, 28 and 56 days respectively with fly ash content. The SCC mixes developed compressive strengths ranging from 25 to 30 N/mm^2, from 37 to 42 N/mm^2 at 7, 28 days respectively with Silica fume content. The compressive strength increased with a decrease in the percentage of the fly ash and the water-to-cementitious materials ratio. Compressive strength increased with a increase in the percentage of the silica fume up to 8% according to these results.

- Splitting tensile strength developed was from 1.5 to 1.9 N/mm^2 and 1.7 to 2.3 N/mm^2 at 28, 56 days, respectively with fly ash content. The SCC mixes developed Splitting tensile strengths ranging from 1.9 to 2.3N/mm^2, from 2.9 to 3.1 N/mm^2 at 7, 28 days respectively with Silica fume content.

- SCC mixes made with fly ash and silica fume are reduced the rapid chloride ion penetrability. The low range (less than 1390 and 1150 Coulomb) at the age of 28 and 56 days respectively with fly ash content and rapid chloride ion penetrability to the very low range (less than 980 Coulomb) at the age of 28 days with silica fume content.

REFERENCES

- Bartos, J.M.(2000). Measurement of Key Properties of Fresh Self-compacting Concrete, CEN/PNR Workshop, Paris.
- Brouwers, H.J.H., Radix, H.J. (2005). Self-Compacting Concrete: Theoretical and experimental study. Cement and Concrete Research vol: 35, pp. 2116 – 2136.
- Schutter,G.De, Bartos, PJM., Domone PLJ, Gibbs JC. (2008). Self-compacting concrete. Whittles Publishing.
- Dehn, F., Holschemacher, K.,Weisse, D.(2000). Self-Compacting Concrete - Time Development of the Material Properties and the Bond Behavior, LACER No. 5, pp.115-123.
- Dhir, R. K., Dyer, T. D. (1999). Modern Concrete Materials: Binders, Additions and Admixtures, Thomas Telford Publishing, London,
- Dinakar, P., Babu, K.G., Santhanam,M.(2003). Durability properties of high volume fly ash self compacting concretes, Cement & Concrete Composites ;30:880-886.
- Domone, P.L. (2006) Self-compacting concrete: An analysis of 11 years of case studies, Cement & Concrete Composites 28,pp 197–208.
- European guidelines for self compacting concrete – specification, production and use; May 2005.
- Ferraris, C.F., L. Brower, J., Daczko, C., Ozyldirim (1999). Workability of Self-Compacting Concrete ,Journal of Research of NIST, Vol. 104, No. 5, pp.461-478.
- Halstead, W. J. (1986). Use of Fly Ash in Concrete, NCHRP Synthesis 127 ."High Reactivity Metakaolin (HRM)". Advanced Cement Technologies, LLC. Metakaolin. http://metakaolin.com/metakaolin/metakaolin-description. Retrieved May 7, 2010.
- Khaloo, A. R., Houseinian, M. R. (1999). Evaluation of properties of silica fume for use in concrete, International Conference on Concretes, Dundee, Scotland.
- Khatib, J.M. (2008). Performance of self-compacting concrete containing fly ash, Construction and Building Materials 22 : 1963–1971.
- Khayat, K.H., Aitcin, P.C. (1987). Silica Fume A unique Supplementary Cementitious Material, Mineral Admixture in Cement and Concrete, Vol.4, by Dr. N.S Ghosh (Ed.)
- Khayat, K.H., Vachon, M., Lanctot, M. C. (1997). Use of Blended Silica Fume Cement in Commercial Concrete Mixtures, ACI Materials Journal, pp.183-192.
- Kosmatka, S.H., Kerkhoff,B., Panarese, W.C. (2002). Design and Control of Concrete Mixtures, 14th Edition, Portland Cement Association.

- Liu,M. (2010). Self-compacting concrete with different levels of pulverized fuel ash, Construction and Building Materials 24:1245–1252
- Mindess, S., Young, J. F., and Darwin, D. (2003). Concrete, Second Edition, Prentice Hall.
- Nehdi M.L., Pardhan, M., Koshowski S. (2004). Durability of self-consolidating concrete incorporating high-volume replacement composite cements, Cement and Concrete Research 34(11):2103-2112.
- Okamura, H., Ouchi, M. (1999). Self-compacting concrete development, present use and future, In: The 1st International RILEM Symposium on Self-Compacting Concrete. Skarendahl A, Petersson O, editors, RILEM Publications S.A.R.L, France. 3-14.
- Okamura, H., Ouchi, M. (2003)a. Applications of self-compacting concrete in Japan. In: The 3rd International RILEM Symposium on Self-Compacting Concrete. Wallevik OH, Nielsson I, editors, RILEM Publications S.A.R.L., Bagneux, France. 3-5.
- Okamura, H. (1997). Self-Compacting High-Performance Concrete. Concrete International, pp. 50-54.
- Oliveira, L. A. P., Gomes, J. P. C., Santos, P. (2005). Study of sorptivity of self-compacting concrete with mineral additives, Journal of civil engineering and management. vol XII, No 3, 215–220
- Ouchi, M. and Hibino,M. (2000). Development, Applications and Investigations of Self-compacting Concrete, International Workshop, Kochi, Japan.
- Ozawa,K., Maekawa,K., Kunishima,M., Okamura,H. (1989). Development of high performance concrete based on the durability design of concrete structures. 445-450.
- Patel,R., Hossain, K.M.A., Shehata,M., Bouzoubaa,N., Lachemi,M. (2004). Development of statistical models for mixture design of high-volume fly ash self-consolidation concrete. ACI Mater J 101(4):294–302.
- Pfeifer, D.W. (1969). Fly Ash Aggregate Lightweight Concrete, Portland Cement Association, R&D Bulletin 003.01T.
- Siddique, R. (2010). Properties of self-compacting concrete containing class F fly ash Materials and Design:32:1501-1507.
- Ramachandran,V.S.(1984). Concrete Admixtures Handbook, Properties, Science, and Technology, Noyes Publications.
- Ray, I., Chattopadhyay,I. (1999). Effect of silica fume on superplasticized concrete, International Conference on Concretes, Dundee, Scotland.

- RILEM TC 174 SCC. (2000). Self compacting concrete State-of-the-art report of RILEM technical committe 174-SCC. Skarendahl A, Petersson O, editors,RILEM Publications S.A.R.L., France. RILEM Publications S.A.R.L., Bagneux, France. 6-14.
- Sahmaran,M., Yaman,O.I., Tokyoy.M.(2009). Transport and mechanical properties of self consolidating concrete with high volume fly ash, Cement & Concrete Composites 31: 99–106.
- Sedran, T., De Larrard, C.F. (1999). Optimization of self compacting concrete -thanks to packing model. In: The 1st International RILEM Symposium on Self-compacting Concrete. Skarendahl A, Petersson O, editors, RILEM Publications S.A.R.L., France. 321-332.
- St John, D. A. (1998). Concrete Petrography, A handbook of investigative techniques, Wiley & Sons, New York.
- Sukumar,B., Nagamani,K., Raghavan.S.R. (2008). Evaluation of strength at early ages of self-compacting concrete with high volume fly ash, Construction and Building Materials 22 : 1394–1401.
- The Concrete Society, BRE. (2005). Technical report No.62 self-compacting concrete: a review. Day RTU, Holton IX, editors, Camberley, UK, Concrete Society, Surrey GU17 9AB, UK.
- Turk,k., Turgut,P., Karatas,M., Benli.A. (2010). Mechanical Properties of Self-compacting Concrete with Silica Fume/Fly Ash, 9th International Congress on Advances in Civil Engineering, 27-30.
- Yazıcı, H.(2007). The effect of silica fume and high-volume Class C fly ash on mechanical properties, chloride penetration and freeze–thaw resistance of self-compacting concrete, Construction and Building Materials 22, 456–462.
- Xie Y, Liu B, Yin J, Zhou S. (2002). Optimum mix parameters of high–strength selfcompacting concrete with ultrapulverised fly ash. Cem Concr Res;32(3):477–80.